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Dynamic Physics

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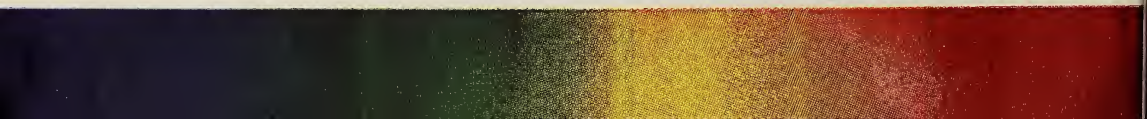
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20th Century-Fox

The picture above, a scene from the motion picture "Western Union," like every other picture involving color, illustrates the effects of the absorption and reflection of light. The reproduction below is the spectrum, which represents an analysis, or breaking down, of white light such as comes from the sun.



Dynamic Physics

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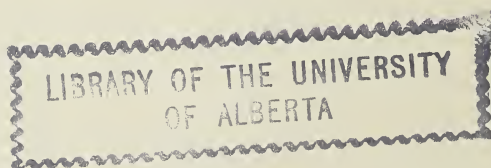
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THE Preface

"Why study physics?"

One purpose of this book is to provide an understanding of the principles of physics necessary to cope with the present mechanized environment. The modern world is a changed world—a world that has been remade by science. This new world is a machine world—a world in which man is surrounded by mechanical devices. During every working hour of the day he is concerned directly and indirectly with machines. He works with them and depends upon their products for food, shelter, and clothing, and even for many pleasures in life. In such an environment every young person needs to know the principles of physics, not alone for successful work, but also for intelligent living.

Another purpose of this book is to help young people lay a foundation for successful careers in the field of science. The progress of science is never-ending. Every day brings new inventions and discoveries that make tomorrow just a little different from today. What the world will be like twenty-five years from now, or even five years from now, no one can safely predict. We know that we are just beginning an air age—a period in which we shall need to become air-minded. Whether we ever fly an airplane or not, it will be worth while to understand the principles by which aircraft operate. Aviation and numerous other fields of endeavor are calling for young men well grounded in science to participate in the progress of the future. Opportunities in the field of new invention were never so great. Also great is the demand for persons to carry on work already under way.

A third purpose of this book is to stimulate critical thinking as a basis for intelligent action in a democracy. We are forever concerned with the preservation of our American way of life. We live in a democracy, a land in which we help to shape human affairs and thus to determine human

THE PREFACE

destinies. To live under the banner of freedom means that we face the responsibility of living coöperatively and successfully with others rather than to ourselves alone. The method of successful living in a democracy is the method of critical thinking or the method of thinking matters through to safe conclusions. Such method eliminates jumping at conclusions, harboring prejudices, yielding to superstitions, and accepting propaganda. Thus a suitable basis is provided for intelligent action—the only sort of action that will perpetuate our American ideals.

In organizing and shaping the content of this book, the authors have been guided by the report of the American Policies Commission. They have sought to point the subject matter of physics in the direction of the four worthy aims laid down as a general pattern for education in a democracy; namely, self-realization, better human relationships, economic efficiency, and civic responsibility. At the same time they have sought to provide a substantial course in physics, one that meets the requirements for college entrance and also embodies preflight instruction in the field of aviation.

The authors have been guided also by the reports prepared by the Committee on Science Teaching as published by the National Education Association. Especially have they accepted the philosophy of science for better living and the principle of molding subject matter to student needs. To these ends the content has been carefully selected in the light of present and probable future importance. The relative emphasis upon various topics has been determined by the relative importance of the topics in modern life. For instance, special attention has been given to the airplane because of its present and forthcoming importance in the field of transportation and to the radio for importance in the field of communication. Likewise, attention has been given to devices in the immediate environment, such as those used for various purposes in the home and in the community.

The title of the book, *Dynamic Physics*, reflects a stimulating presentation of the subject matter—a method that makes the content interesting, meaningful, and purposeful to the learner. Under this method the facts and principles of physics are presented in such a manner that the student sees a reason for learning. In other words, he learns because he wishes to learn—because he sees in the subject matter of physics something to challenge his thinking and something suited to his needs.

THE PREFACE

The content is divided into twelve units in each of which the materials are closely related to a fundamental theme. The first unit is introductory and provides a picture of the broad scope of physics, a preliminary discussion of matter and energy, and an explanation of measurement in relation to physics. Each succeeding unit, except the last, covers a regularly accepted division of physics, such as mechanics, heat, sound, electricity, light, or an appropriate part thereof. The last unit discusses electromagnetic waves and radioactive elements, thus providing an insight into the nature of the unexplored physical universe. The units present the subject matter of physics in the customary order of teaching, but they may be interchanged readily if the teacher prefers another order of treatment.

Each unit opens with an appropriate introduction to orient the learner in the subject matter treated. The content is divided into areas, each of which treats a definite phase of the unit, and thereby enables the learner to concentrate his efforts and to proceed from one phase to another in a systematic manner. At the end of each area are questions that enable the learner to check his mastery of facts and principles, and there are usually problems to test his understanding of applications that require mathematics. The problems in most cases are presented in A and B lists. The A list represents minimum essentials and the B list assignments of greater difficulty for students capable of handling additional work. Each unit closes with a condensed summary, a set of challenging questions, a list of survey problems, and suggestions for practical investigations.

In addition to the foregoing features, attention is directed to the glossary, the appendix, and the index. The glossary is distinctive because: (1) the list of technical terms is comprehensive, including all those encountered in the course; (2) the definitions are simple; broad explanations are substituted in many instances for short statements; (3) no undefined terms are included in the definitions. The appendix is complete for study purposes, including standard tables for reference, tables of conversions and equivalents, and a list of abbreviations of terms. The index, besides being complete, is carefully designed to enable the user to locate topics with a minimum of time and effort. Under the heading of formulas, the index provides immediate guidance to the full treatment of any formula the use of which is desired. The index indicates the number of pages and the number of illustrations devoted to each topic in the text.

Special care has been given to illustrations. The text is provided with excellent line drawings to help clarify facts and principles. These draw-

THE PREFACE

ings are placed in close proximity to the related context and may be considered an integral part of the context. Particularly useful is the effective way in which the drawings help the pupil to understand the formulas used. The text is also abundantly provided with half-tones that help to relate facts and principles to everyday life. Other half-tones show high-school students carrying on laboratory experiments related to the context. These photographs show actual equipment used in high-school physics laboratories. They should have both a practical and an inspirational value to students of physics.

The authors and the editor express their grateful appreciation for valuable assistance from widely scattered sources as follows: (1) high-school students for their reactions to the subject matter in experimental materials; (2) high-school teachers for their helpful criticism of the materials; (3) industrial agencies for information on procedures and research; and (4) public agencies, especially the Civil Aeronautics Administration and other departments of the United States government for consultation in the field of aviation.

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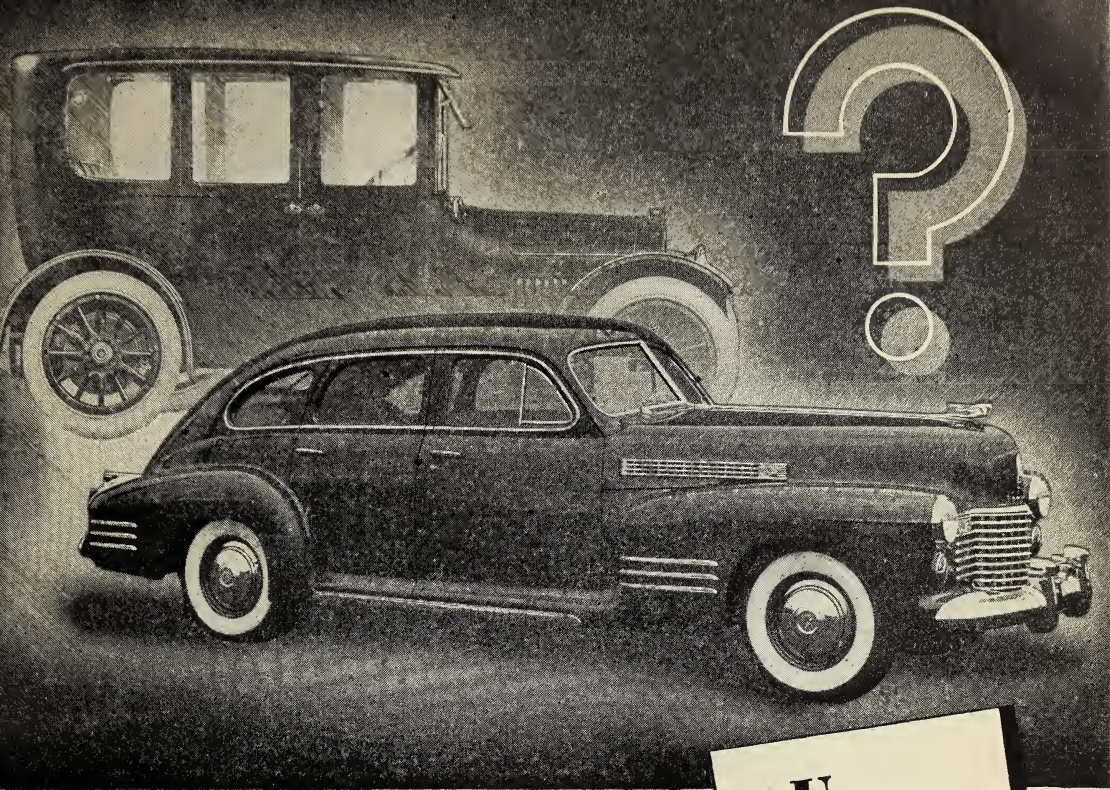
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Dynamic Physics





General Motors Sales Corporation

The automobile owner of a generation ago could not have visualized the beautiful modern car shown above. Likewise we today are unable to visualize the car of the future.

Looking at Physics in Relation to Life

THE OLD AND THE NEW

Which automobile above looks the more natural, the more like automobiles upon the highways today? The dull automobile in the background, a strange-looking vehicle in comparison with the more attractive one in front, represents the automobile which your father observed when he was your age. The question mark at the right indicates the uncertainty of the automobile

UNIT
ONE

LOOKING AT PHYSICS IN RELATION TO LIFE

of the future. Nobody knows exactly what this automobile will be like, but one thing is certain, that it will be considerably different from the automobile of today.

The change in automobiles is typical of changes that have occurred in all forms of transportation. This is a day of sleek streamline trains and huge air liners, but your father at your age never observed such swift conveyances. All railroad trains in his youthful days were like the older and slower trains today, and the airplane was only a novelty. Probably his only opportunity to view an airplane was at an exhibition or fair where spectators craned their necks in wonder as the crude mechanism roared about overhead.

Changes of similar character have taken place also in the field of communication. The radio, telephone, and telegraph transmit messages almost instantaneously, and airplanes and railroads carry mail with the greatest dispatch—all breaking down the barriers of distance with the utmost ease. When your father was your age, the radio was scarcely more than an experimental toy. Farther back, when your grandfather was young, even the telephone and the telegraph were little used, the telephone being new and the telegraph being maintained largely by railroads for dispatching trains.

The changes which have taken place in transportation and communication are representative of progress in all phases of living. This progress, much of which may be attributed to scientific endeavor, has ushered in a new era of living, an era in which man is surrounded by machines. These machines have enabled him to attain a high standard of living, higher than he has ever experienced before. All this is good, of course, but it charges him with great responsibility, for he must make important adjustments to a mechanized environment. In order to make these adjustments successfully, he must learn how to use machines to advantage and how to avoid their hazards. In other words, he must come to know science, for science explains the underlying principles of machine operation and thus helps to bring about an understanding of mechanized environment.

PHYSICS CONCERNED WITH LIFE

This unit will introduce you to the science of physics, which has helped to bring about the present high standard of living. It will show how physics is related to life, explain some of its underlying principles, and thus lay a foundation for the units to follow. More specifically, it will direct your attention to the following areas of study.

AREAS OF STUDY

- 1. How is the science of physics related to life?*
- 2. How is physics concerned with matter and energy?*
- 3. How is physics concerned with measurement?*

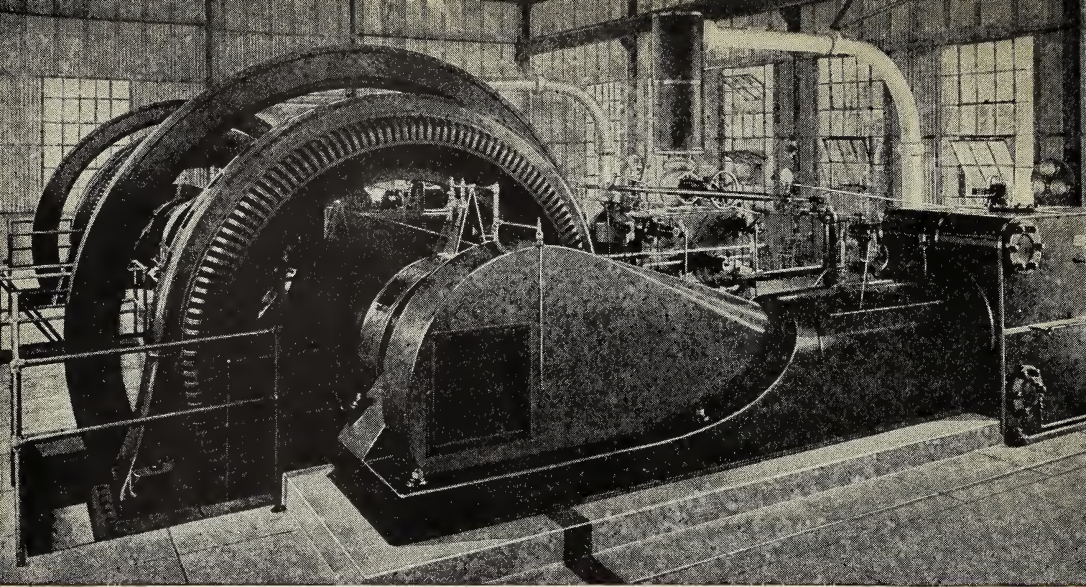
AREA ONE

How Is the Science of Physics Related to Life?

According to a famous saying handed down from the past, “you never miss the water till the well runs dry.” This saying explains our tendency to take things for granted, to overlook the importance of things even though they play a vital role in our existence. Among the many things that we take for granted are the benefits of science. Accordingly, let us begin our study of physics by considering its relation to life. First of all, let us see exactly what physics is.

THE NATURE OF PHYSICS

The science of physics is very broad, being made up of five separate divisions commonly known as mechanics, heat, sound, electricity, and light. Each of these divisions constitutes a large area of investigation and study in relation to life. The next few pages will discuss each division briefly.



Ferdinand Hirsh

Steam, acting as a force, runs this modern engine and thus supplies power for developing electricity. The electricity produced is used in running the machines of the factory.

Physics concerned with mechanics. The term *mechanics* refers to forces acting upon objects in such a way as to cause motion or to oppose motion. The force may act upon a liquid such as water, a gas such as air, or a solid such as a lever or a machine. A ship, for instance, acts as a force when it plows through the water of the sea and causes the water to move out of the way. A pump in a city water system acts as a force when it drives water through the mains to places of use. An air pump at a filling station acts as a force when it compresses air for inflating automobile tires. A workman acts as a force when he uses a lever for lifting heavy objects. Steam acts as a force when a steam engine turns the wheels of a machine in a factory. Electricity acts as a force when an electric motor drives a lathe in a machine shop. The brakes on a railroad train act as a force when they bring the train to a stop. These are only a few of the examples of mechanics that might be given, for the field is very broad, accounting for thousands of occurrences in everyday life.

Your study of machines will help you to understand how man harnesses liquids, gases, and solids and puts them to work. In other words, it will explain the principles underlying the opera-

PHYSICS CONCERNED WITH LIFE

tion of numerous machines that you have occasion to use or that others use for your benefit day after day. Also, it will clear up many questions about things around you, things that may have seemed strange and made you wonder. Among the questions which you will find answered are such as the following:

What enables a swimmer to float even though his body uncontrolled would sink in the water?

How do liquids in hydraulic brakes help to stop an automobile?

When you drink through a straw, what causes the liquid to rise to your mouth?

Why is air, which is only a gas, used in tires to support the weight of an automobile?

Why does a pump with a long handle work more easily than one with a short handle?

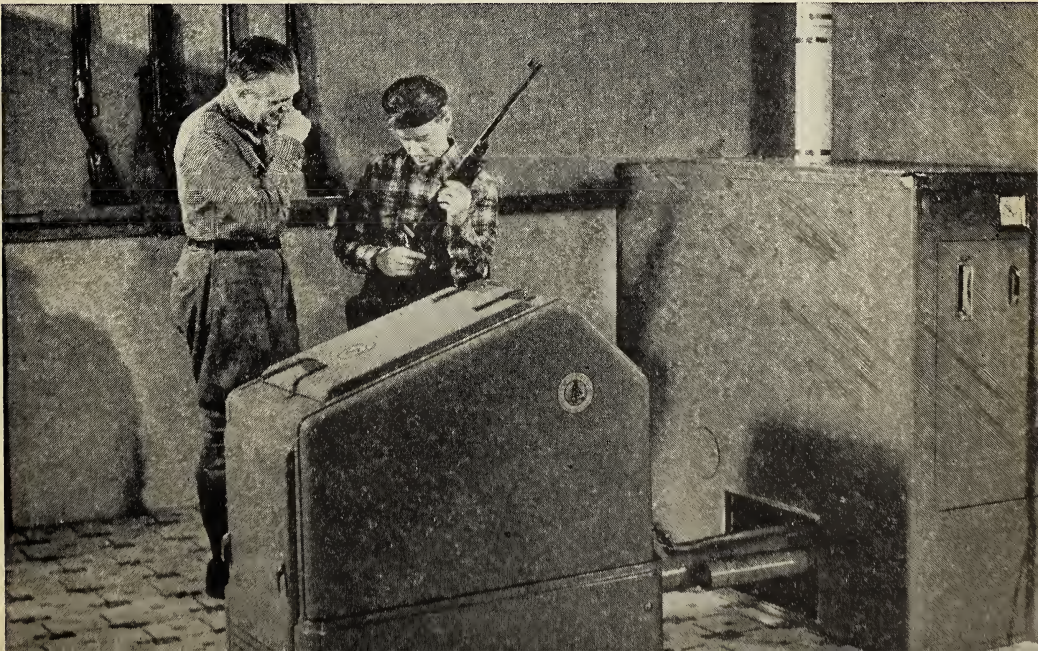
Why must the lighter of two persons sit on the longer end of a seesaw or teeterboard?

What is meant by the horsepower of an engine?

Physics concerned with heat. Heat is a form of energy, often called heat energy, which travels everywhere, both through space and through material things. The great source of heat is the sun, as we well realize on a hot summer day. Man uses heat in

This stoker-type heating unit heats an entire house to any desired temperature. The cleanliness and compactness of the heating unit permit the basement to be used as a pleasant recreation room. The basement in this picture is used for a gun room.

Iron Fireman Manufacturing Company



LOOKING AT PHYSICS IN RELATION TO LIFE

a variety of ways—to cook his food and to keep him comfortable at home, to help him carry on work, and also to secure many forms of pleasure. Thus he has designed various heat-producing contrivances such as stoves, hot-air furnaces, steam-heating plants, and many others. Within recent years he has also taken steps to protect himself from heat when it becomes too intense. To accomplish this purpose he has devised air-conditioning units that regulate the temperature of public buildings, such as theaters, hotels, and restaurants, many homes and offices, and even railroad cars and busses. Both the contrivances that supply heat and the ones that combat it operate according to certain well-defined principles of physics.

Your study of heat will help you to understand the nature of heat, how it behaves, and how man uses it as a servant in everyday life. It will enable you to understand numerous heat contrivances so that you may use them intelligently. As in the case of machines, it will explain various manifestations in your environment and answer many questions that may have caused you to wonder. Among these questions are such as the following:

How is heat “stored” in a chunk of coal?

How does the sun, even during cold weather, supply sufficient heat for plants in a greenhouse?

Why can a person start a fire by rubbing two sticks together?

How does an ordinary thermos bottle keep a hot drink hot or a cold drink cold?

Why can ice be kept on an indoor skating rink even at ordinary room temperature?

Why does ice cream freeze faster when salt is put on the ice used in the freezer?

Why is wool clothing warmer than cotton clothing?

Physics concerned with sound. Sound is a form of energy often called sound energy, which travels freely through the air and more or less readily through all material things. Like heat, it helps man in a variety of ways, especially in the field of oral communication. Every time he chats with his family in the home, converses with a friend on the street, carries on an interview in his office, or uses the telephone, he depends upon sound. Sound



Ewing Galloway

With his trumpet this young man is able to produce a series of sounds in a musical sequence. All music is produced according to definite principles of physics.

also helps man by enabling him to enjoy music. Whether he sings a song, plays a violin, cornet, or piano, or merely listens to melodious strains over the radio, he relies upon sound. In addition, sound helps man by providing him with signals, as when a whistle or bell calls him to work or warns him of danger. In fact, it contributes so much to life that we can scarcely comprehend its benefits. What a dreary world this would be without speech, without music, or even without whistles and bells!

The study of sound will explain the nature of sound, how it originates and travels, and how man uses it to satisfy his interests and needs. You will find this study especially interesting because sound is a curious phenomenon that affects both the physical and the emotional sides of your life. Because of its baffling nature at times, you will probably approach the study with many questions, such as those on the following page.

LOOKING AT PHYSICS IN RELATION TO LIFE

What is the difference between music and noise?

How is sound produced by a steam whistle? by an automobile horn? by a bell?

How is sound "preserved" in a phonograph record?

Why can you hear more distinctly in some auditoriums than in others?

Why do you hear thunder one or more seconds after you see the lightning?

Why is a violin or a guitar built with a hollow body?

Physics concerned with electricity. Another form of energy that you will study in physics is the wonder-working "force" known as electricity. This energy, which has come into use in recent times, exerts a great influence upon modern life. Flowing mysteriously over wires to countless places of use, it performs a multitude of tasks, supplying heat, light, and power. In the home it floods the rooms with light, cooks the food, and operates such labor-saving devices as washing machines, irons, and vacuum cleaners. In the factory it supplies light for the workingmen, heat for smelting ores, and power for running machines. In the field of transportation it propels the trolley car and assists in the performance of the Diesel engine of railroads and the internal-combustion engine of automobiles. In the field of communication it helps to operate the radio, the telephone, and the telegraph.

Much has been done with electricity within recent years to lessen the drudgery and monotony of housework. The picture below shows a modern kitchen where the housewife does many things with electricity to save herself both time and energy.



PHYSICS CONCERNED WITH LIFE

The study of electricity will explain how electrical energy originates, how it behaves under ordinary conditions, and how man uses it in everyday life. You should find this study especially helpful, for you need to know how to use electricity intelligently, not only to enjoy its benefits, but also to avoid its dangers. Moreover, since electricity is of a mysterious nature, you may have accumulated numerous questions, such as the following, which you wish to have answered:

How does lightning differ from the electricity used in lighting buildings and streets?

How does an electric current travel over wires such as those in a high-tension line?

What keeps the filament or wire in an electric-light bulb from burning out?

Why is very little heat produced in electric wiring and much heat produced in an electric toaster?

How does a short circuit differ from any other kind of electric current?

Why is it dangerous to insert a coin or other piece of metal in a fuse box when a fuse burns out?

How does electricity turn an electric motor?

Physics concerned with light. Still another form of energy that you will study in physics is light, sometimes called light energy. Despite the fact that other forms of energy are important to man, light is perhaps the most important of all, for it enables him to see and thus to learn most about his environment. Light also enables him to enjoy color, which accounts for much of the beauty in the world. Imagine, if you can, what the world around you would be like without color! Realizing the importance of light, scientists have provided man with devices to aid vision, such as spectacles, mirrors, microscopes, and telescopes. They have also devised better methods of lighting homes, office buildings, and factories and have contributed greatly to the enjoyment and use of a variety of colors.

Your study of light will enable you to understand something of the nature of light, how it behaves, and how man uses it in the ordinary activities of life. It will enable you to understand certain

LOOKING AT PHYSICS IN RELATION TO LIFE

instruments for making adjustments to light and for deriving greater benefits from light—instruments that you may be using at present or probably will use in the future. As in other divisions of physics, the study of light will clear up many questions about your environment, such as the following:

Why do objects appear smaller when observed at a distance than near at hand?

Why does any object such as a stick appear bent when it projects from the water?

Why do objects such as flowers have different colors?

Why do curved mirrors make a person look fat, thin, tall, or short?

What is the difference between a telescope and a compound microscope?

How does a periscope work?

What causes a rainbow?

PHYSICS IN RELATION TO PROGRESS

To understand further how physics is related to life, let us briefly outline the story of man's civilization. The progress of man depends greatly upon certain developments within the field of physics. These developments have caused man to think differently, to work differently, and to live differently. In other words, they have served as steps by which he has climbed to the high place that he occupies today in civilization.

A long period of ignorance, superstition, and fear. In former times, from the dawn of history down to a few centuries ago, the world was filled with ignorance. Lacking modern instruments of study, man knew little about the universe. Having limited means of travel, he knew little about the earth. Strangely, he knew little about his own surroundings or even his own body. One reason for his ignorance was his lack of understanding of natural causes, such as the causes of seasons, storms, and disease.

Because of man's ignorance of the causes of various happenings around him, he was dominated constantly by superstition and fear. He believed, for instance, that many things happened because of certain gods and goddesses, some of whom were good, some bad, and some partly good and partly bad. One god, known

as Apollo by the ancient Greeks, rode across the sky in a chariot and provided the light of day. Another, known as Zeus, rode on a thunder-car and hurled thunder and lightning. A goddess, known as Demeter, caused crops to grow in the fields, and another, known as Iris, produced the rainbow.

Besides having such beliefs as these, man put great faith in foolish customs and sayings. He believed that certain acts or events foretold good luck and certain others bad luck. To help him interpret various occurrences and predict the future, he often consulted soothsayers, persons who claimed to have contact with the gods and hence to know all things well. To conquer disease, he often called upon witch doctors who claimed to have the power to drive out evil spirits. Thus man became the victim of many quacks who profited by his ignorance.

Despite the ignorance in the world, there were many deep thinkers, especially among the Greeks and the Romans. These thinkers, commonly known as philosophers, considered various problems of life but attempted to settle them entirely by argument or discussion. They attached little importance to investigation, and often penalized persons for performing experiments. On one occasion, according to an old story, certain wise men met to discuss the question "How many teeth has a horse?" The argument went on for weeks and at times became quite heated. Finally a wag, overhearing the argument, decided to end the disturbance by actually counting the teeth of a horse and reporting his findings. This he did, but to no avail. The wise men merely had him thrown into prison and continued their debate.

One of the greatest thinkers of early times was the Greek philosopher Aristotle, who influenced many people by his teachings. He was especially interested in science and came to conclusions that were accepted as true, not only in his own time but for long years afterward. One of his most notable conclusions, a conclusion that was later disproved, was that a heavy weight always drops faster than a light one. Another conclusion that he reached, and which was later disproved, was that light is propagated through a transparent medium.



Bettmann Archive

This picture shows Johannes Gutenberg, at the right, explaining his movable type to a friend who was greatly interested in its use.

A period of broadening horizons. About the time when Columbus discovered America, man began to broaden his horizons. One influencing factor was the compass, which had been invented many years before but which was greatly improved about 1200 A.D. by the Italians. Prior to 1300 A.D. the compass was of little value, but after its improvement sailors began to take their ships far from shore. Traveling far-

ther, they began to discover new lands and to realize that there were no monsters in the sea, as they had come to believe. Moreover, they obtained their first true understanding of the earth as a globe, for up to this time most people, including some of the most learned of the time, had thought that the earth was flat.

The second factor that helped man to broaden his horizons was the invention of the printing press. Printing of some sort had been done for centuries, but the process was slow and laborious. Finally during the fifteenth century a man named Johannes Gutenberg, of Germany, invented movable type that could be used much as type is used in modern times. This invention enabled printers to use type over and over rather than throw it away as before and hence to produce far more reading materials than formerly. As a result, more people learned to read and consequently acquired more information.

The rise of critical thinking. As people broadened their horizons they began to think more intelligently than before; that is, to consider problems more scientifically and hence to draw more logical conclusions. In other words, they began to search for the "why" and "how" of things in the world. This search led

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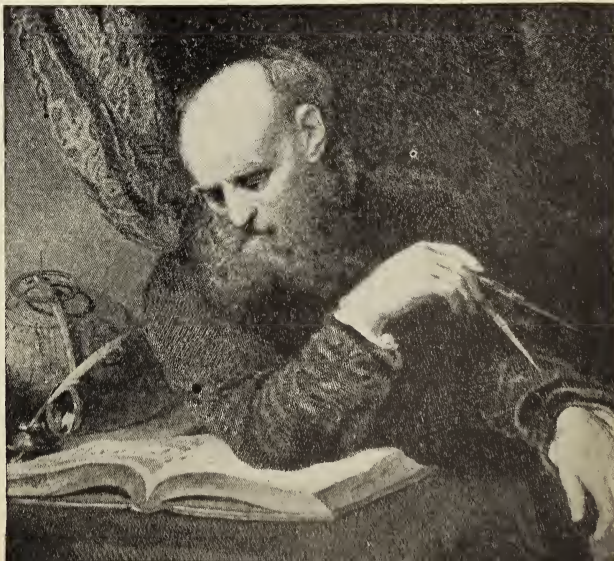
them to discover that many statements of the old philosophers needed to be revised. One of the leaders who challenged these statements was an Italian teacher by the name of Galileo. This teacher, who served as professor at the University of Pisa, decided among other things to check the statement of Aristotle that heavy objects fall faster than light objects. Accordingly, he dropped two iron balls, one much heavier than the other, from a tall tower in the city known as the leaning tower of Pisa. Both balls struck the ground at exactly the same time, proving that the old statement was wrong. This experiment attracted wide attention, for disputing a statement so generally accepted was considered almost sacrilegious.

Scientific method, such as Galileo applied to the problem of falling bodies, is the essential element of modern scientific investigation and procedure. The scientific method as applied today is made up of certain well-defined steps. Let us see what these steps are and how Galileo's famous experiment of early times illustrates their usefulness. The steps are as follows:

1. *Recognizing the Problem.* Does a heavy body fall through the air faster than a light body of similar shape and density?
2. *Tentative Ideas or Hypotheses.* (a) All similar bodies fall at the same rate, or (b) heavy bodies fall faster than light ones.
3. *Reasoning on the Basis of Tentative Ideas.* If (a) is true, two iron balls of different weights will fall at the same rate. If (b) is true, they will fall at different rates.

Galileo (1564-1642)

The famous Galileo was born near Florence, Italy. As a student at the University of Pisa, he found many fallacies in old-time teachings, began to experiment, and made a variety of discoveries. Later, as a professor at Pisa, he made further discoveries, especially in the fields of physics and astronomy, advanced new principles, and made a number of important inventions.



LOOKING AT PHYSICS IN RELATION TO LIFE

4. *Experimentation and Observation.* Actual dropping of the two iron balls from the top of the leaning tower.
5. *Conclusion Based on Experiment.* When dropped simultaneously, a heavy body and a light body of similar shape and density fall at the same rate.

Galileo probably had none of the foregoing steps in mind as he carried on his experiment, but he evidently considered his problem much in this manner. At any rate, his method helped him to seek the truth and thus to break down misconceptions of the past. Since his time critical thinking has helped other scientists to study natural phenomena and thus to solve problems to the benefit of man. Such thinking, however, is not limited to the field of science but may be applied to any problem situation that arises in everyday life. It has a place in the home, in the community, and especially in a democracy such as ours where every citizen has a voice in public affairs. Therefore every reader of this book should develop the habit of thinking critically, not only as an aid in pursuing this course in science but also as an aid in everyday living.

The succeeding pages tell briefly about some of the inventions that have helped the world to progress since the time of Galileo. Back of each invention is a story of critical thinking on the part of the inventor—how he recognized a problem, formulated hypotheses, reasoned intelligently, performed an experiment, and drew a conclusion. Such thinking may have lasted over a period of years, in some instances only one man working on a problem but in most instances several men, each contributing something to the final solution. As you read, note the evidences of critical thinking back of each invention—thinking that carried the inventor on until he produced something that would “work.”

Opening up new worlds through the telescope and the microscope.

Besides testing ideas handed down from the past, Galileo applied himself in numerous other directions. For one thing, he studied the use of lenses, constructing both a telescope and a microscope. Similar instruments, however, appeared in Holland, the telescope



Ewing Galloway

Thousands of laboratories similar to the one pictured above are equipped with microscopes and other instruments through which technicians look at the unseen world.

commonly being credited to Lippershey, and the microscope to two brothers named Janssen and to a man named Leeuwenhoek, who later made important refinements. The first models, of course, were very crude, but they opened up new worlds never seen before. The telescope enabled man to formulate his first true picture of the universe, and hence broke down many of the superstitions expressed in myths and legends from the past. The microscope enabled him to look upon tiny forms of life hitherto unknown and also to understand better the structure of natural things. Thus it served to break down many misbeliefs and laid the foundation for Pasteur's discovery, some years later, that certain organisms cause disease.

Harnessing a mighty force in the steam engine. Much critical thinking was applied to the force of steam before a way was found of putting it to work. Little progress was made until about

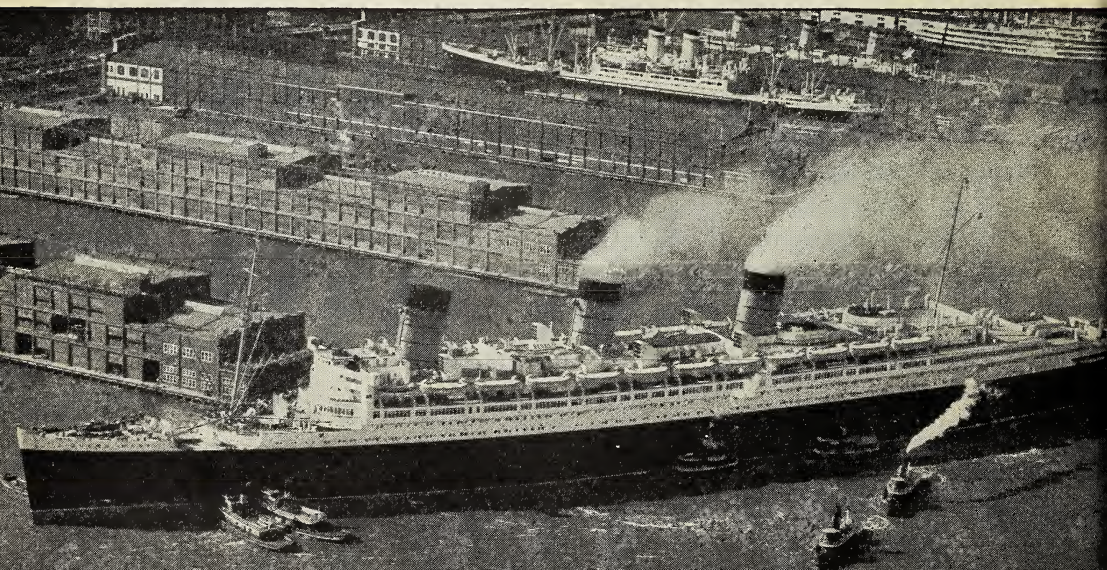
LOOKING AT PHYSICS IN RELATION TO LIFE

1700, when two pioneer inventors, a Frenchman by the name of Papin and an Englishman by the name of Newcomen, developed engines with pistons moving back and forth in cylinders. Both engines operated with great loss of steam, however, and hence were of little practical value, but the Newcomen engine, which was much the better of the two, was used for pumping water from coal mines. About 1765 a Scotch instrument maker at the University of Glasgow by the name of James Watt, while repairing a Newcomen engine, became interested in the problem of reducing the waste of used steam. As a result, he devised a model that passed the used steam into a condenser, somewhat as engines operate today. This engine was a great improvement over its predecessors, but much refinement was necessary before it could be put into everyday use. With the refinements completed, about 1781, steam power was introduced in spinning factories and gradually took over much of the work of the world. Only within recent times has it had real competition in its field.

Building gigantic travelers—the steamboat and locomotive. Shortly after the steam engine came into practical use, certain forward-looking men began to think critically about using steam power in transportation. One of the leaders in this movement was Robert Fulton, who sought to apply the power to a boat. Accord-

This picture shows the *Queen Mary*, one of the largest steamships in the world, being docked at a pier by tugboats in the harbor at New York. Steamships such as this carry passengers and goods between all the important seaports of the world.

James Sawders



ingly, in 1807 he launched his famous *Clermont* on the Hudson River and prepared for a test. Many curious people gathered along the banks to watch the ungainly craft, some believing that it would never move. To their surprise, however, the paddles began to turn and the boat slowly plowed its way upstream. A short time later other steamboats appeared, especially on the Ohio and Mississippi rivers, where they played an important part in settling the Middle West.

The first locomotive, or engine designed to run on rails, was built in England in or about 1804 by Richard Trevithick. Other and more efficient models were built later by George Stephenson and his son Robert, also of England. The first locomotive in America, known as the *Tom Thumb*, was built in 1829 by Peter Cooper. This locomotive, which had an upright boiler and looked much like a handcar, created a great stir among the people. Many were skeptical of the puffing device, thinking that it could never take the place of the horse. During the next few years, however, railroads were built in numerous regions, especially in the region of cities east of the Appalachian Mountains. Later they were extended to the west and south, where they helped to open up great areas of the country for settlement.

Saving "elbow grease" with the cotton gin and the reaper. While the afore-mentioned men were taking steps to improve transportation, others were considering means of reducing manual labor. A pioneer thinker in this direction was Eli Whitney, a young schoolteacher who taught in the cotton region of the South. Observing the slow hand process of separating cotton fibers from seed, he attempted to devise a machine for the purpose. As a result, in 1793 he invented the cotton gin, a machine that has continued in use ever since. This invention, by eliminating hours of labor, helped to reduce the price of cotton so that the poor could wear cotton clothing as well as the rich. Following the invention, the demand for cotton increased, cotton raising became profitable, and the South became the leading cotton-producing region, not only in America, but in the whole world.

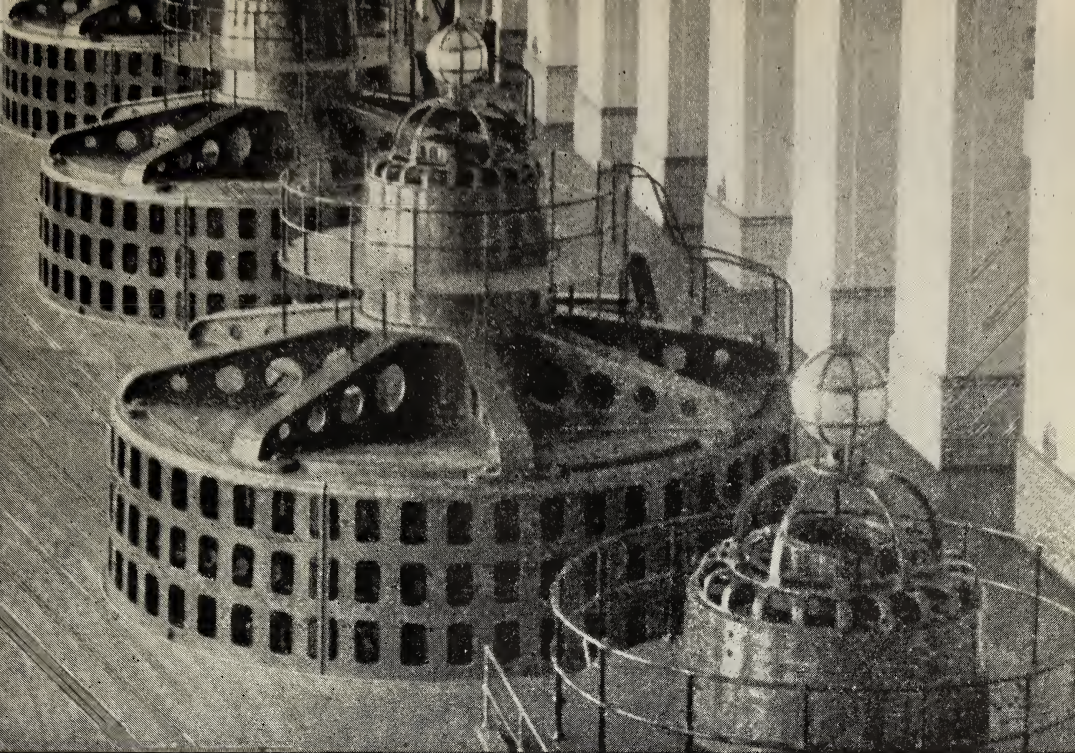
LOOKING AT PHYSICS IN RELATION TO LIFE

Another person who applied critical thinking to the problem of reducing manual labor was Cyrus H. McCormick. This famous inventor, noting the laborious task of cutting grain with a cradle, undertook the problem of building a harvesting machine. At length in 1831, after many years of experimenting, he developed a machine known as a reaper, which cut standing grain and dropped it onto a platform from which it could be raked and bound into bundles. This machine proved a great boon to agriculture, especially in the rich grain region of the Middle West, commonly known as the "breadbasket of the nation." Since that time, the reaper has been greatly improved and in many instances displaced by the combine, but the original invention marked a distinct step in the progress of the country.

Breaking down barriers with the telegraph and the telephone.

For many years the progress of the world was retarded by poor communication. The only means of sending messages was by letter, and in most instances mail traveled very slowly. Days and even weeks elapsed before the people in one place knew what was happening in another, even though the places were fairly close together. Finally, a man named Samuel F. B. Morse began to study the problem critically and in 1844 startled the world by inventing the telegraph. In testing the device he transmitted the message "What hath God wrought?" and broke down barriers of both time and distance. The telegraph was put into use almost immediately and soon began to tick off messages in all parts of the country, especially along railroad lines.

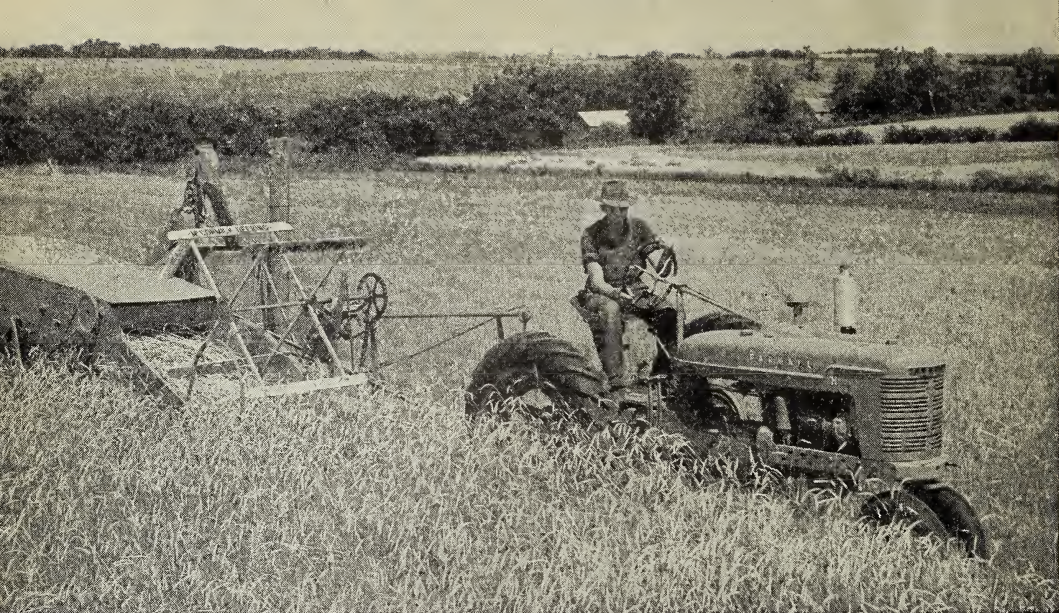
About forty years after Morse designed the telegraph, another critical thinker, Alexander Graham Bell, invented the magical device known as the telephone. His first model transmitted only indistinct sounds, but it served to bolster his faith in the idea. As a result, he kept on experimenting and in 1876 produced a model which withstood every test. The telephone then came into service, but, requiring a complicated system of wiring, was introduced rather slowly. Today, it is the most widely used and the most convenient form of communication known.



Ferdinand Hirsh

This is a picture of a hydroelectric plant. The machines shown in the picture are turbines through which water power is transformed into electricity. The electricity is then carried by power lines to communities where it runs machines and provides light and heat.

Developing new forces through the electric generator and the internal-combustion engine. As machines grew in importance in the world, certain prominent thinkers began to look for new sources of power. Some turned to electricity, but as yet nobody knew how to produce electricity in quantity. At length an Englishman by the name of Michael Faraday and an American by the name of Joseph Henry discovered that a rapidly moving magnet would induce an electric current in a near-by coil of wire. This discovery, which served as the germ of an idea, encouraged scientists to experiment over a long period of years. Finally, in 1866 a German by the name of Werner von Siemens, applying the idea, devised an electric generator. Thus the problem was solved, and before many years the wonder-working force known as electricity was busy running trolley cars, lighting city streets, and performing countless other tasks for man.



International Harvester Co.

The power that drives the tractor shown in the above picture is provided by an internal-combustion engine. Such an engine is of great help to the farmer, for it enables him to do many times the work that he once did by old-fashioned means.

While these scientists were developing the electric generator, others were attempting to produce an internal-combustion engine. The idea of utilizing the force of an explosion had attracted attention for years, but nobody knew of a practical means of producing the force. Numerous and varied attempts were made, but each resulted in failure. Nevertheless the idea lived on, and about 1850 a Frenchman named Étienne Lenoir invented an engine that developed power through the explosion of natural gas. Slightly later a German named Nicholas Otto devised the "four-stroke cycle" used in most engines today. The internal-combustion engine, like the electric generator, marked a great step in progress and before long helped man in a variety of ways.

Conquering distance with the automobile and the airplane. Shortly after the internal-combustion engine came into use, certain critical thinkers began to consider the problem of using it to propel small vehicles, such as the buggy or carriage. Several men produced motor vehicles in Europe, and in 1894 Charles

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B. Duryea, commonly considered the father of the American automobile, produced the first model in this country. The public was greatly interested in the new vehicle and promptly labeled it the "horseless carriage." Within a few years the automobile came into general use and since that time has revolutionized the world. Today it is the most widely used vehicle in the world, serving people in both business and pleasure.

While the automobile was being developed, another and even more startling form of transportation came into being. Since earliest times man had wanted to fly, but little was accomplished in this direction until the time of Orville and Wilbur Wright. These air-minded individuals conceived the idea of flying a glider-like contrivance under the power of a gasoline engine. They experimented over a period of years and finally in 1903 built the first flying machine. The crude craft stayed in the air only a few seconds, but sufficiently long to demonstrate that their idea would work. Thus they continued to experiment and others became interested, gradually developing the highly efficient product that we see today. Like the automobile, the airplane has helped to transform the world, causing distances "to shrink" so that the most distant places may be reached in a few days.

The modern airplane is a far cry from the primitive model that the Wright brothers took into the air. The graceful modern airplane roars through clouds or above the clouds. It can be held to its course by means of the miraculous radio beam.

United Air Lines



LOOKING AT PHYSICS IN RELATION TO LIFE

Enriching life with the radio and motion picture. During the latter part of the nineteenth century an Italian scientist by the name of Guglielmo Marconi began to work on the problem of sending electric signals by wireless. After years of experimenting, he succeeded in sending messages for short distances and at length in 1901 astounded the world by sending a message across the Atlantic Ocean. A few years later other scientists interested in wireless communication devised a means of transmitting sound, first by wireless telegraph and then by radio. Their first results were far from satisfactory, but they kept on bringing about improvements until they produced a highly efficient device. Today the radio serves man in wondrous ways, contributing both to his economic efficiency and to his pleasure.

About the time Marconi and others were experimenting with wireless, other men were attempting to produce motion pictures. The first man to achieve success in the venture was Thomas A. Edison, who invented a celluloid film and a crude motion-picture machine. About 1894 other scientists devised a projector for throwing pictures upon a screen, and the foundation was laid for public exhibitions. More than thirty years later, in 1926, sound effects were introduced, and today the motion picture fills an important place in the world, providing man with wholesome recreation and cultural information.

Summarizing the benefits of physics. Thinking back over what you have read, you can see that physics has made, and is still making, a great contribution to the world. Delving into the fields of mechanics, heat, sound, electricity, and light, it helps man to understand his environment and hence to think critically of problems growing out of his surroundings. Also, because of the numerous inventions that function according to its principles, it helps him to maintain an exceedingly high standard of living.

Besides the foregoing, physics helps man to realize other benefits of importance. Through the X-ray, the fluoroscope, and the microscope, for instance, it helps him to understand disease and thus to maintain good health. Through electric signals, color

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devices, and air brakes, it helps him to live safely—to avoid accidents. Through the steam engine, the internal-combustion engine, the electric generator, and other machines, it helps him to understand numerous vocations in life. Through the radio, motion picture, and camera, it helps him to obtain wholesome recreation. Through its consideration of contrivances and tools, it helps him to purchase goods intelligently. Through its explanation of numerous principles, it helps him to practice conservation, such as the conservation of eyesight and food. Through its interpretation of the mechanized environment, it helps him to establish a wholesome outlook upon life. Through this interpretation, likewise, it helps him to make desirable adjustments to surrounding conditions. Finally, it enables him to coöperate better with other members of society and hence to participate successfully in the American way of life.

ANSWER THESE QUESTIONS

1. What are the five major divisions of physics?
2. Why were the people of early times filled with superstition and fear?
3. Why were many of the conclusions of old philosophers erroneous?
4. What is meant by scientific method and what important steps does it involve?
5. What notable experiment represents one of the first applications of critical thinking?
6. How did critical thinking help to break down much of the superstition and fear of the past?
7. How did the telescope and microscope pave the way for more critical thinking in the world?
8. How have inventors, by critical thinking in the field of physics, developed important sources of power?
9. How have inventors applied critical thinking in physics to bringing about better means of transportation?
10. How have inventors used critical thinking in physics to provide better communication?
11. How have inventors contributed to wholesome recreation?
12. What are some of the specific benefits of physics in everyday living?

LOOKING AT PHYSICS IN RELATION TO LIFE

AREA TWO

How Is Physics Concerned with Matter and Energy?

From the preceding discussion we have obtained a preliminary understanding of the science of physics. If we were to ask a scientist what physics is, he probably would say that it deals with the relation between matter and energy. What would he mean by the term *matter*, however, and what would he mean by *energy*? First, let us consider his concept of matter.

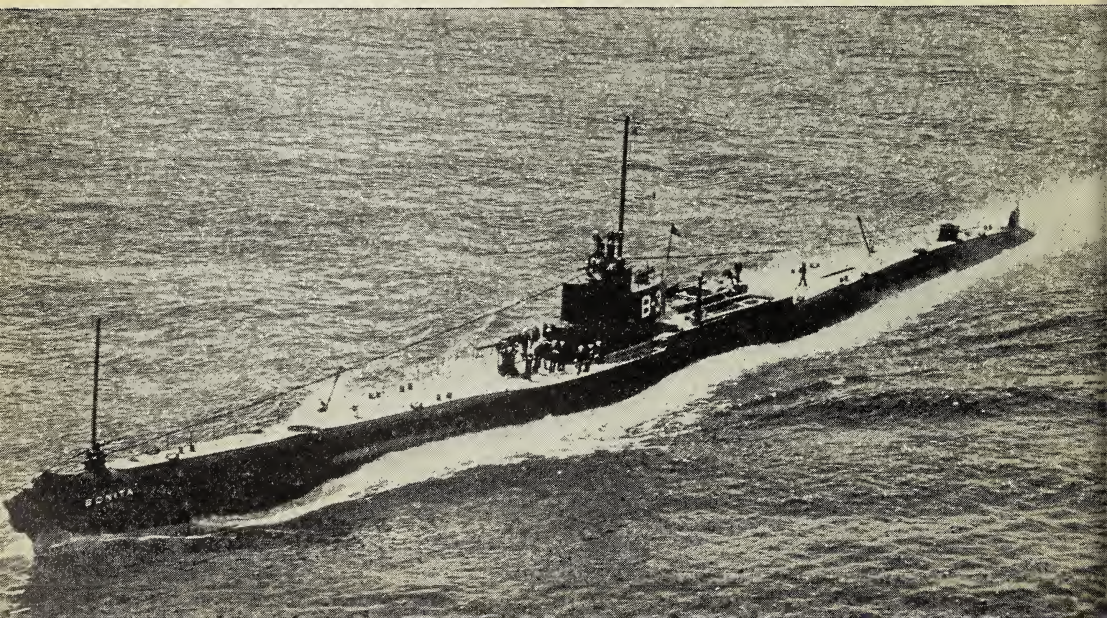
WHAT IS MATTER?

Matter is anything that occupies space. It may be something that we readily observe, as a streetcar or book, or something that we detect with difficulty, as the fumes from a gasoline engine. Moreover, it may be a natural resource, as iron ore, or a man-made product, as a locomotive.

Matter in three important states. Matter exists in three forms, or states—as solids, liquids, and gases. A solid is matter in rigid or fairly rigid form. When we handle a solid, it retains its volume and shape sufficiently to be identified. If we move a chair from

The action of a submarine depends upon the three states of matter. Its hull is a solid, which travels upon or within a liquid, and its compartments contain gas.

James Sawders





Ferdinand Hirsch

This picture shows matter at work. The tractor, a solid, derives its power from a liquid that is transformed into a gas. The explosion of the gas provides the necessary power.

one side of the room to another, for instance, or occupy it for hours, we may still recognize it as the same chair. It has changed very little from our handling. A liquid is matter in flowing form. When we handle a liquid, it retains its volume, except for slight evaporation, but not its shape. If we pour coffee from a coffee-pot into drinking cups, we have approximately the same quantity of coffee, but the shape is modified to fit the containers. A gas is matter that retains neither volume nor shape and tends to escape in the air. If we open a bottle of ammonia gas in a laboratory, we may soon detect the odor in all parts of the room. On the other hand, we may greatly compress a gas, or cause it to occupy less space, as when we inflate an automobile tire. From these explanations we can see that an understanding of the three states of matter is very important, for it helps to explain great differences in the behavior of physical things.

The ninety-two elements, or building blocks, of matter. Matter is made up of ninety-two simple substances that we may think of as building blocks. These simple substances, or building blocks,

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make matter different just as different kinds of bricks make buildings different. Some matter, the simplest kind, consists of one element alone, as oxygen or sulfur. Other matter consists of two or more elements chemically combined, known as compounds, such as water, which contains hydrogen and oxygen. Still other matter consists of two or more elements that remain distinct from one another but together form mixtures, such as air, which contains principally nitrogen and oxygen. Thus we see that the elements, through themselves, their compounds, and mixtures, give matter great variety and account for thousands of material things in our environment.

Composition of Matter

The scientist explains the composition of matter on the basis of theory rather than upon direct observation. No microscope enables him to study the structure of matter minutely enough for the purpose, and therefore he must draw conclusions about this structure from the behavior of matter under varying conditions. Even so, his conclusions have been tested over a period of years and virtually established as fact.

Matter composed of particles known as molecules. If we were to break any matter, such as stone or coal, into smaller and smaller particles and could continue the process long enough, we should finally come to tiny particles known as molecules. Molecules are the smallest particles in matter that retain the characteristics of the matter itself. They are far too small to be seen with a microscope, nor could they be seen well if they were a thousand times larger. Contrary to what one might expect, they are loose from one another but are held more or less closely together by a strange attraction of one for another. Contrary also to expectation, they are constantly in motion, their movement somewhat resembling that of balloons bouncing against one another in space.

Some matter contains far more molecules per unit of volume than other matter, the molecules being crowded together more closely with less space between. They are most numerous, of

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course, in solids, less numerous in liquids, and still less numerous in gases. In the case of solids they are held closely together by attraction, in liquids less closely together by attraction, and in gases only faintly by attraction. Thus we can readily see why solids are more or less rigid, why liquids may be poured, and why gases escape into the air.

After reading the foregoing, we may wonder why the scientist believes in the molecular theory. One proof comes from the ordinary experience of filling an automobile tire with air. The tire is low, according to the molecular theory, because it contains comparatively few molecules with large spaces between. When the attendant forces air into the tire, he crowds more molecules into the tube, and these molecules cause the tire to become harder and harder. Belief in molecules helps us to understand why the automobile can ride on air.

Another proof comes from the experience of smelling food, such as a beefsteak cooking on a stove in the kitchen. According to the molecular theory, certain molecules escape from the cooking

Whenever we stop at an automobile service station, we might address the attendant somewhat as follows: "Mister, will you please put more molecules into my tires?"

Century Photos



LOOKING AT PHYSICS IN RELATION TO LIFE

beefsteak into the air. These molecules move out in all directions and some of them come into contact with the olfactory nerve in the nose. Knowledge of molecules, then, helps us to understand why we detect the presence of materials through smell.

Molecules made up of atoms. For many years after the molecular theory was advanced, scientists thought that molecules were more or less solid and the smallest particles that there could be. Near the beginning of the nineteenth century, however, a noted scientist by the name of John Dalton advanced the theory that molecules are made up of still smaller particles known as atoms. Since that time further evidence has been secured, with the result that the theory is now universally accepted. According to the atomic theory, each element has an atom of its own. The atoms combine with one another to form molecules of various substances or material things, such as water, sugar, and rubber. Such combinations account for more than a million substances found in our physical environment.

Strange to say, despite the fact that atoms are still smaller than molecules, scientists have calculated their size and weight. The atoms of some elements are supposed to be larger than the atoms of other elements and known to be heavier than the atoms of other elements. Thus an atom of chlorine is thought to be larger than an atom of hydrogen and also is known to be heavier. An atom of average size and weight, such as the oxygen atom, is supposed to be less than one hundred-millionth of an inch in diameter and to weigh one hundred-million-million-millionth of a pound. The hydrogen atom is supposed to be the lightest atom of all, and the uranium atom the heaviest.

As in the case of the molecular theory, we may wonder what evidence there is that atoms exist. The chief evidence is the fact that they help to explain the chemical structure of matter and especially what happens in the case of chemical change—how substances break up and how substances combine to form other substances. In other words, they help to lay a foundation for the important branch of science known as chemistry.

PHYSICS CONCERNED WITH MATTER AND ENERGY

Even atoms made up of smaller particles. When Dalton advanced the atomic theory, he considered atoms the smallest particles of matter, but more recently scientists have concluded that there are still smaller particles. According to present belief each atom contains a nucleus around which particles known as electrons revolve, somewhat as the earth and other planets revolve around the sun. The nucleus carries a positive charge of electricity and the electrons carry negative charges. These opposite charges result in an electrical attraction between the nucleus and electrons that holds the atom together.

Each nucleus is supposed to contain three kinds of particles, known as protons, neutrons, and positrons. The protons carry positive charges of electricity, which account in large measure for the positive charge of the nucleus as a whole. The neutrons are slightly heavier than the protons, each neutron consisting of a positively charged proton and a negatively charged electron. The positive charge on the proton offsets the negative charge on the electron, with the result that the neutron carries no charge. The positrons, like the protons, carry positive charges of electricity, but their particular function is somewhat uncertain.

The particles vary greatly in number in atoms of different elements, an atom of one element containing more particles than an atom of another element. An atom of sodium, for example, contains eleven protons in the nucleus and eleven electrons that revolve around the nucleus. An atom of carbon contains six protons in the nucleus and six electrons that revolve around the nucleus. An atom of oxygen contains eight protons in the nucleus and eight electrons that revolve around the nucleus. As these atoms indicate, the number of protons, regardless of the element, is always the same as the number of electrons. In addition to the electrons and protons in an atom, there are usually varying numbers of neutrons and positrons.

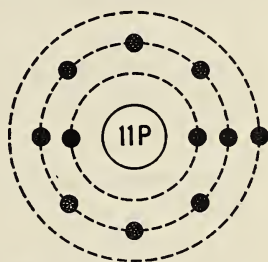


Fig. 1. Sodium atom showing relation of the protons in the nucleus to the electrons outside.



Ferdinand Hirsh

The above picture shows an outside view of a cyclotron. Through its use men hope to understand better the nature of matter.

Sometimes, as in the case of chlorine, an element has two kinds of atoms, one weighing more than the other. The heavier atom weighs more than the lighter atom because there are more neutrons in the nucleus. The number of protons in each atom is always the same as the number of electrons.

Within recent years scientists have developed great interest in an experiment known as smashing the atom. One of the leaders in this work is E. O. Lawrence, of the University of California, who has devised a machine called the cyclotron. This machine hurls particles of matter against a background at such speed that it causes atoms to break into parts. The particles

thus obtained help to verify the atomic theory and also to explain the behavior of matter under varying conditions.

Regardless of change, the quantity of matter is always the same.

Matter constantly undergoes change, either through the efforts of nature or under the influence of man. Any change in which the molecules retain their original nature is said to be physical, and any change in which the molecules modify their composition is said to be chemical. If we dissolve salt in water, the salt molecules and the water molecules remain the same; or if we freeze water, the molecules remain the same. Both these changes are physical. On the other hand, if we burn coal in a stove, the molecules break up and the atoms recombine to form carbon dioxide and other substances. Again, if we mix hydrogen and

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oxygen under certain conditions, the molecules break up and the atoms recombine to form water. Both these changes are chemical.

Regardless of any change that takes place, whether physical or chemical, the quantity of matter always remains the same. In other words, a person may change matter from one form to another or from one kind to another, but he never gains or loses matter in the process. This fact, which is of special importance in both physics and chemistry, is known as the *law of the conservation of matter*. Stated specifically, the law is as follows: *Matter cannot be created or destroyed.*

The Properties of Matter

Every kind of matter has certain properties that help to distinguish it from other kinds of matter and also to determine its usefulness. Aluminum, for example, is light and therefore good for making airplanes, whereas iron is heavy and good for making locomotives. The following pages will discuss the general properties of matter with which we shall be concerned later.

Volume a first property of matter. Since matter takes up room, or occupies space, it always has volume. In the case of solids we compute the volume by taking measurements and applying certain rules. Thus we determine the volume of a rectangular solid by obtaining the product of the height, breadth, and thickness. In the case of liquids, we compute the volume differently, for liquids have no fixed dimensions. Accordingly, we determine the

These logs, which illustrate clearly how matter occupies space, will soon be converted into lumber, paper, or other useful products, for the benefit of man.

Canadian National Railways



LOOKING AT PHYSICS IN RELATION TO LIFE

volume of a liquid by computing the size of the container or by pouring it into a measure such as a pint cup. In the case of gases we use still other methods, for gases are very elusive. These methods, which are more complicated than those mentioned for solids and liquids, will be explained later. The main point to keep in mind at this time is that the volume of all forms of matter, even gases, may be measured.

Mass a second property of matter. Mass refers to the quantity of material in an object, or the condensation of molecules. Some forms of matter have greater mass than others, for the molecules are closer together. In general, solids have a greater mass than liquids, and liquids have a greater mass than gases. The mass always remains the same except when matter is modified by chemical change. We may hammer a piece of metal into a sheet, but the hammering does not change the quantity of material. Likewise, we may freeze water into ice, but the freezing does not affect the quantity of material. In both cases the number of molecules remains the same.

Weight a third property of matter. All matter is attracted by the earth, the attraction being indicated by a pull toward the center known as gravity. This pull causes objects to have weight, which we commonly measure with devices known as scales. Some objects weigh more than others, partly because the pull is greater for their kind of matter and partly because they have greater mass or contain more material. Weight always decreases with elevation. In other words, an object weighs more at sea level than it does on a mountain and more on a mountain than it does above the mountain. An airplane weighs many pounds more on the ground than it does in flight several miles high.

Impenetrability a fourth property of matter. By impenetrability we mean that one object cannot occupy the same space as another object. This property helps to explain why collisions take place, as when two automobiles run together on the highway



Ewing Galloway

As this young woman propels her way through the water, she causes the water to make room for her body. The water closes in again when her body has passed.

or two persons jostle each other on the sidewalk. Many collisions, of course, are not especially noticeable, for one object gives way to another. When a person swims, he collides with water, but he scarcely realizes it, for the water makes room for his body. If he lands flat upon the water, however, in diving, he realizes full well that something has happened. When a person takes a stroll out of doors, he collides with air, but the air readily makes room for his body. If he walks into a strong wind, on the other hand, he realizes that the air takes up room. If he carries an umbrella, as in a storm, he realizes it still more, for the wind may turn his umbrella wrong side out. Thus matter in all states, whether solids, liquids, or gases, is impenetrable.

Inertia a fifth property of matter. Inertia is the tendency of matter at rest to remain at rest and of matter in motion to remain in motion. All matter remains at rest or in motion until acted upon by an outside force. How well we realize this fact if we fail to open a door when we pass from one room to another. The door, having no will of its own, remains perfectly still until we bump into it. Similarly, we may see the effect of inertia when we carelessly throw a baseball toward a window. We might as well expect the shatter of glass, for the ball has no power to stop

LOOKING AT PHYSICS IN RELATION TO LIFE

suddenly in the air. Inertia, like weight, depends greatly upon mass. The greater the mass, the greater the inertia, and the less the mass, the less the inertia. This fact helps to explain why an iron bar is harder to use than a wooden stick of the same size or why a baseball is harder to stop than a handball.

Porosity a sixth property of matter. When we take a bath, we often soak a washcloth with water and then squeeze the water out, repeating the process over and over. We use the washcloth in this manner because it has great porosity, or large air spaces between the threads. Likewise, because of porosity we dunk a doughnut in coffee or milk or use a blotter to take up ink. Porosity varies greatly in matter, some substances, such as those already mentioned, having large openings and others, such as iron and stone, having practically no openings except between molecules. In general, gases are more porous than liquids, and liquids are more porous than solids.

Special properties of matter. Besides the properties aforementioned, which belong to all forms of matter, there are other properties that belong only to certain kinds of matter. Tenacity, for instance, causes matter, such as steel or chromium, to have great strength. Brittleness causes matter, such as glass or chalk, to break easily. Hardness enables certain matter, such as a diamond or steel, to cut other materials. Ductility enables certain matter, such as copper or gold, to be drawn into a wire. Malleability enables certain matter, such as iron and copper, to be hammered or rolled into sheets.

Density of Matter

Frequently in handling or using substances, we say that some are more compact than others. By *compactness* we refer to how closely the particles of matter are crowded together. Although we may not realize it, we really refer to the closeness of molecules, a compact substance having the molecules relatively close

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together and a less compact substance having the molecules farther apart. To consider the important subject of compactness, the scientist regularly uses the term *density*.

Density a measure of mass per unit volume. The term *density* refers to the mass or quantity of material in a unit volume of substance, as in a cubic inch of water or a cubic foot of concrete. The only means of indicating density is in terms of weight, and consequently it is expressed in pounds, ounces, and other similar measures. The density of water, for instance, under normal conditions is approximately 62.4 pounds per cubic foot or 0.58 ounces per cubic inch. This simply means that if we weigh separately all the tiny particles in a cubic foot of water, we should have 62.4 pounds of material.

To find the density of a substance, we merely divide the total weight by the volume. The scientist commonly expresses the computation by means of a formula in which D stands for density, W stands for weight, and V for volume as follows:

$$D = \frac{W}{V} \text{ or } DV = W.$$

Example. Suppose that we wish to find the density of a block of wood which is 1 ft. wide, 6 in. deep, and 8 ft. long and which weighs 130 lb. We first find the number of cubic feet in the block, namely, 4 cu. ft., and then substitute the proper numbers in the above formula as follows:

$$D = \frac{130}{4} \text{ or } 4D = 130.$$

Therefore $D = 32.5$ pounds per cubic foot.

The densities of substances vary slightly with changes in temperature and pressure. In general, since most substances expand or increase in volume somewhat when heated, their densities slightly decrease. Thus water at 39° Fahrenheit or above expands a trifle when heated, and its density falls slightly below 62.4

LOOKING AT PHYSICS IN RELATION TO LIFE

pounds per cubic foot. When pressure is applied to substances, the exact reverse is true—they shrink or decrease in volume and their densities increase. Thus when pressure is applied to water, its density rises slightly above 62.4 pounds per cubic foot. The densities of substances also decrease slightly with elevation because of the pull of gravity, and hence their weights decrease with increasing distances from the center of the earth. Thus the density of water falls slightly below 62.4 pounds per cubic foot if taken up on a mountain or up in an airplane.

How density is used. One of the greatest uses of density is to compare one object with another. Often we say that one material is heavier than another, as that iron is heavier than wood. Such a statement, however, is inaccurate, for we fail to say how much iron we have in mind or how much wood, and manifestly a large chunk of wood may weigh less than a small piece of iron. What we really mean to say is that the density of iron is greater than the density of wood, for on such a basis we compare the weights of equal volumes, as the weight of a cubic inch of iron with the weight of a cubic inch of wood. The accompanying illustration, Figure 2, indicates the densities of three common substances: lead, gold, and water. On the basis of these densities how many times heavier is lead than water? How many times heavier is gold than water? How many times heavier is gold than lead?

Since density is an index of weight, it is an important factor in construction. Architects and engineers make wide use of density in determining the weight of materials to be used in



Fig. 2. The three drawings above indicate the weights of equal volumes of lead, gold, and water.

the construction of buildings, bridges, and machines. By multiplying the weight of a unit volume—in other words, the density—of steel, concrete, or other

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substances by the total number of units to be used, they can tell exactly what the structure will weigh. With this information at hand, they can determine the kind of foundation, truss, or other device needed to support the structure.

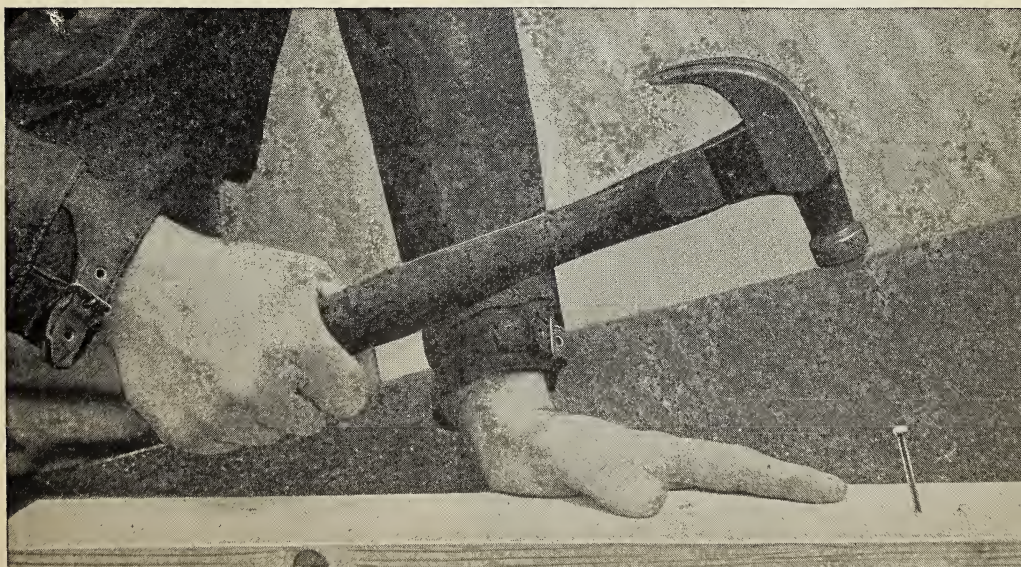
WHAT IS ENERGY?

Earlier we learned that the science of physics deals with energy in relation to matter. Already you have a general idea of what energy is, having used the term a great many times. Now let us compare your idea of energy with what the scientist says about the term. This topic is very important, for energy accounts for everything that happens in the world.

Energy the capacity for carrying on work. Energy is always associated with matter and may be defined as the capacity for doing work. A waterfall has energy, for it has the capacity to turn a water wheel. Wind has energy, for it has the capacity to turn the blades of a windmill. A raised hammer has energy, for it has the capacity to drive a nail. A wound watch spring has energy, for it has the capacity to turn the wheels of the watch. Much energy is stored away in natural products such as coal, wood, and petroleum. Energy is also stored away in food and in the muscles of the human body.

Whenever a person drives a nail with a hammer, he makes use of energy from two principal sources: first, the energy stored up in the hammer because of its raised position, and second, the energy stored up in the muscles of his arm.

Ferdinand Hirsch



LOOKING AT PHYSICS IN RELATION TO LIFE

Energy exists in different forms. One of the chief forms is mechanical energy, which is acquired through the action of outside forces. Water acquires mechanical energy when it is pumped into a water tower, for it takes on the capacity of exerting pressure. A watch spring acquires mechanical energy when the watch is wound, for it takes on the capacity of running the wheels of the watch. Other forms of energy besides mechanical energy are heat, sound, electricity, and light. Matter acquires these forms of energy in various ways, and all, as we shall find later, may be translated into work. Heat energy, for instance, causes steam to expand and thus through the steam engine to pull railroad trains and to turn the wheels of factories. Electrical energy causes an electric motor to operate and thus to run streetcars, factory machines, and vacuum cleaners.

When the scientist defines energy as the capacity for doing work, he has in mind a slightly different work from the kind which causes fatigue. From the standpoint of physics, work involves putting matter in motion, retarding matter in motion, or changing

The energy stored in the wound main-spring of a watch causes the watch to run.

Ferdinand Hirsh



the direction of matter in motion. According to this concept of work, a man does work when he lifts a sack of wheat or basket of cotton to his shoulder, but he does no work when he merely stands holding the load. Nor would he do any work if he stood holding the load for a great many hours. Similarly a man does work if he pushes an automobile and causes it to move, but he does no work if he pushes in vain. Even if he drops from exhaustion, he does no work so long as the vehicle remains still. In other words, he must produce motion in order to do work.



Ewing Galloway

The archers in this picture have given potential energy to their bow strings by placing them in position to do work. When the strings are released, this potential energy will be transformed into kinetic energy, and the arrows will fly through the air.

Energy changes constantly from one form to another, and man has devised many machines and contrivances to bring about changes. In fact, the transformation of energy is the chief underlying principle of most inventions in the world. The steam engine, for instance, is a machine for transforming heat energy into mechanical energy. An electric generator is a machine for transforming mechanical energy into electrical energy. The electric light is a device for transforming electrical energy into light energy. Thus the story continues.

Energy classified as potential and kinetic. For purposes of study, energy is generally separated into two classes—potential and kinetic. Potential energy is energy that an object possesses because of its position, condition, or composition. A boulder on the edge of a cliff or a loose brick on the edge of a chimney possesses potential energy because of its position. A tightly coiled spring or a stretched rubber band possesses potential energy because of its condition. A chunk of coal or a gallon of gasoline

LOOKING AT PHYSICS IN RELATION TO LIFE

possesses potential energy because of its composition. Other examples of objects that possess potential energy are a swimmer poised on a diving board, a hammer raised in the air, compressed air in a tank, a bent bow, a loaded gun, an unlighted match, an engine under steam, and an electric cell.

Kinetic energy is the energy that an object possesses because it is in motion. An automobile possesses kinetic energy as it skims over a highway, and the faster it goes, the more energy it possesses. A football player possesses kinetic energy when he dashes down the field with the ball. Other examples of objects that possess kinetic energy are a boy throwing a stone, a man chopping wood, a hammer striking a nail, a coil unwinding, a horse running a race, a tractor pulling a load, a train moving along a track, an airplane winging its way, a steam engine turning the wheels of a factory, and a combine harvesting grain.

Energy may be transformed readily from one kind to the other; that is, potential energy may be changed to kinetic, and kinetic energy may be changed to potential. For example, when a stone rolls down an incline, such as a hill, or a coiled spring unwinds, potential is changed to kinetic. On the other hand, when a person carries a stone up an incline or winds a coiled spring, kinetic energy is changed to potential.

Energy said to be indestructible. Many times in the past man has attempted to build a perpetual-motion machine, or one that will run itself. Every such experiment has failed because indirectly he has attempted to create energy. No machine will run perpetually, because there is no way of overcoming friction. Therefore any machine must have energy not only to cause it to start but to offset friction as it runs. The more energy that a machine has, the more work it will do.

Just as man has been unable to build a perpetual-motion machine, so has he been unable to create energy in any other manner. Likewise, he has never been able to destroy energy by any of his activities. Every time that he changes energy from one form to another, he has just as much energy as he

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had in the beginning. At times he may think that he modifies the quantity, as in the burning of coal, but if he measures the heat and other energy products, he will find that he has just as much energy as before. The fact that the quantity of energy always remains the same is known as the *law of the conservation of energy*. Stated specifically, this law is as follows: *Energy cannot be created or destroyed.*

ANSWER THESE QUESTIONS

1. What is matter?
2. What are the three states or forms of matter?
3. How do the elements serve as building blocks in matter?
4. According to the molecular and atomic theories, how is matter composed?
5. What evidence is there that atoms and molecules exist?
6. How does physical change differ from chemical change?
7. What is the law of the conservation of matter?
8. What are some of the more important properties of matter?
9. What is density and how is it determined?
10. What is energy?
11. What are some of the important kinds of energy?
12. How is energy classified into two large groups?
13. What is the law of the conservation of energy?

SOLVE THESE PROBLEMS

A

1. The water in a tank occupies 8 cu. ft. of space and weighs 499.2 pounds. What is the density of the water in pounds per cubic foot?
2. A stone contains 3 cu. ft. and weighs 900 pounds. What is the density of the stone in pounds per cubic foot?
3. A watering trough contains 10 cu. ft. of water. How much does the water weigh in pounds if its density is 62.4 lb. per cubic foot?
4. A block of lead is 4 ft. long, 3 ft. wide, and 2 ft. thick. How many tons does the block weigh if its density is 708 lb. per cubic foot?
5. A block of ice is 3 ft. long, 2 ft. wide, and 18 in. thick. How many pounds does the block weigh if its density is 56 lb. per cubic foot?
6. A piece of plastic 3 ft. long, 6 in. wide, and 1 in. thick weighs 6 pounds. What is its density?

LOOKING AT PHYSICS IN RELATION TO LIFE

B

7. A block of balsa wood 4 ft. long, 12 in. wide, and 6 in. thick, weighs 15 pounds. What is its density in pounds per cubic foot?

8. A storeroom is 40.2 ft. long, 20.8 ft. wide, and 12 ft. high. How many pounds of air does the room contain if the density of the air is 1.2 oz. per cubic foot?

9. The density of concrete is 150 lb. per cubic foot. On this basis, how many tons of concrete will be required to build a wall 20 ft. long, 8 ft. high, and 8 in. wide?

10. A log at a sawmill weighs 1,240 pounds. How many cubic feet does it contain if its density is 70 lb. per cubic foot?

11. A sphere of granite is 8 ft. in diameter. How much does the sphere weigh if its density is 175 lb. per cubic foot?

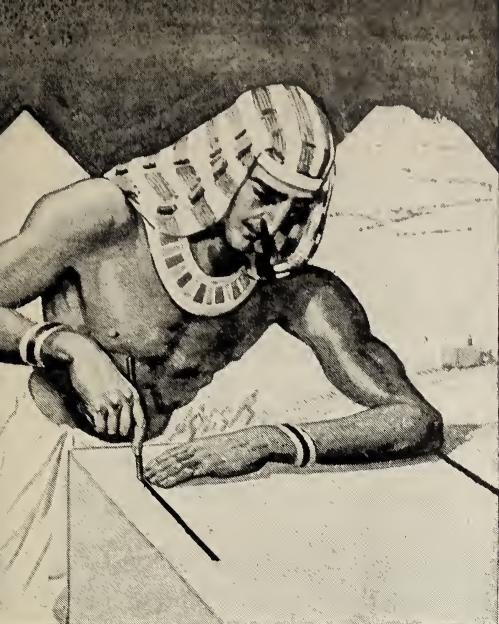
12. The cast iron in a cubical mold weighs 32,768 pounds. If the density of the iron is 462 lb. per cubic foot, what is the length in inches of each edge of the mold?

AREA THREE

How Is Physics Concerned with Measurement?

Measurement plays a vital role in life and we use it in nearly everything that we do. Without it we would become hopelessly tangled, for it constitutes the basis of exchange. When we purchase groceries, we ask for measured quantities of food products and measure out money in return. Likewise, when we stop at a filling station, we ask for measured quantities of gasoline and oil and measure out the payment. Measurement also plays an important part in physics, being applied to both matter and energy, the two important factors with which physics is concerned.

The English system of measurement. The system of measurement which we ordinarily use in this country is known as the English system because it was standardized in England. The chief units of length in the English system are the inch, foot, yard, rod, and mile; the chief units of weight are the ounce, pound, and ton; and the chief units of capacity are the pint, quart, gallon, and bushel. These units are familiar to nearly every person in the land—in fact, so familiar that we use them almost habitually. Not



Ferdinand Hirsh

The picture on the left shows an Egyptian measuring his forearm to indicate a cubit, and the picture on the right, a Greek indicating a digit by the width of his finger. These crude methods were among the earliest attempts at accurate measurement.

only do they provide a simple basis for the exchange of goods but also a basis for thinking quantitatively.

The English system, despite its extensive use, is considered very cumbersome from the standpoint of science. The reason for this condition is the fact that the units originated haphazardly rather than by planning. For example, the units of linear measurement came into being largely through comparisons with parts of the body. One of the earliest units of length was the cubit, which seems to have originated among the ancient Egyptians. This unit represented the length of the forearm from the elbow to the tip of the middle finger. Since forearms differed, the unit was very inaccurate, but it was generally accepted as about eighteen inches long. The ancient Greeks, who lived slightly later in history, originated the digit, which was about three-fourths inch long. They also divided the foot into twelve equal parts, each part representing the width of the thumb nail. The Romans added the mile from the practice of walking to measure long distances, the mile being the same as a thousand paces, or double steps.

LOOKING AT PHYSICS IN RELATION TO LIFE

The English added still other units, such as the palm, which was about three inches long, the span, which was about nine inches long, and the foot, which was twelve inches long, the latter being one of the more important units in use today. They also added the yard from the practice of measuring cloth by holding it between the nose and the end of the extended arm. During the reign of Queen Elizabeth in the sixteenth century, the units were standardized by government authorities and have continued in much the same form ever since. The English system at present is most widely used in the United States, Great Britain, and certain parts of the British Empire.

The metric system of measurement. Another system of measurement is the metric system, which originated in France about a century and a half ago. This system, unlike the English system, was carefully planned and hence is far less cumbersome. The chief units in the metric system are the meter for length, the liter for capacity, the gram for weight, and the second for time. The larger units in each table are formed by the use of Greek prefixes, as follows: *deca* or *deka*, meaning 10; *hecto* or *hekto*, meaning hundred; and *kilo*, meaning 1000. The smaller units are formed by the use of Latin prefixes, as follows: *deci*, meaning $\frac{1}{10}$; *centi*, meaning $\frac{1}{100}$; and *milli*, meaning $\frac{1}{1000}$. Under such an arrangement each unit in any table is ten times larger than the next smaller unit, or one-tenth as large as the next larger unit. Computation is simple because we may change units to higher or lower denominations merely by shifting the decimal point. The metric system is used in practically all parts of the world except the United States and Great Britain, where it is used for scientific purposes only.

The metric system is extensively used in all the divisions of physics. This science, as we shall find later, requires exact measurements of both matter and energy. In many instances, the English system is too cumbersome for the purpose. Therefore we should prepare to use the metric system efficiently in our work by reviewing some of the unit measures at this time.

PHYSICS CONCERNED WITH MEASUREMENT

The meter—standard unit of length. The chief unit of length in the metric system is the meter, which is approximately 39.37 inches in length. This unit was fixed arbitrarily, the exact measurement being scratched on a bar of platinum-iridium preserved in the International Bureau of Standards at Sèvres, France. Practically all countries have made copies of this bar, our own standard bar being preserved in the National Bureau of Standards at Washington, D. C. Officially the meter is defined as the distance between the two marks on the bar when its temperature is the same as the freezing temperature of water. The unit must be defined in this manner because the bar changes slightly in length with the temperature. The complete table for linear measure according to the metric system is given below. One of the more important smaller units in this table is the centimeter, which is extensively used in physics. Figure 3 shows how the centimeter compares with the inch, an inch being 2.54 centimeters long.

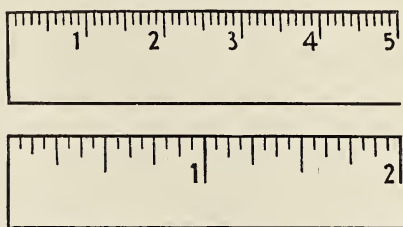


Fig. 3. Five centimeters and two inches are practically equivalent in length.

1000 meters	= 1 kilometer (km.)
100 meters	= 1 hectometer (hm.)
10 meters	= 1 decameter (Dm.)
meter	(m.)
.1 meter	= 1 decimeter (dm.)
.01 meter	= 1 centimeter (cm.)
.001 meter	= 1 millimeter (mm.)

If we wish to convert meters into millimeters, according to the above table, we merely multiply the number of meters by 1000, or move the decimal point three places to the right. Hence, 125 meters = 125,000 millimeters. If we wish to convert meters into kilometers, we merely divide the number of meters by 1000, or move the decimal point in the number three places to the left. Thus, 125 meters = .125 kilometers.

LOOKING AT PHYSICS IN RELATION TO LIFE

As in the case of linear measure in the English system, linear measure in the metric system may be readily converted into square measure and cubic measure. Square measure is used for indicating areas, the chief units being the square meter (sq. m.) and the square centimeter (sq. cm.). Cubic measure is used for measuring volume, the chief units being the cubic meter (cu. m.) and the cubic centimeter (c.c.).

In the case of square measure, each unit is one hundred times larger than the next smaller unit, or one one-hundredth as large as the next larger unit. Therefore in changing a unit to the next smaller denomination, we multiply by 100, or shift the decimal point two places to the right. Hence 125 square meters = 12,500 square decimeters. In changing a unit to the next larger denomination, we divide by one hundred, or shift the decimal point two places to the left. Thus 125 square meters = 1.25 square deca-meters. In the case of cubic measure, each unit is one thousand times larger than the next smaller unit, or one one-thousandth times as large as the next larger unit. Hence we convert units from one denomination to the next smaller by multiplying by 1000 and to the next larger denomination by dividing by 1000.

The liter—standard unit of capacity. The chief unit of capacity in the metric system is the liter, which contains 1000 cubic centimeters or one cubic decimeter. The liter and other units of



Fig. 4. The three measures of capacity represented by these drawings differ but little in size.

capacity are used for measuring both solids and liquids. In this respect they differ from the English system, in which dry quarts and bushels are used for measuring solids and liquid quarts and gallons are used for measuring liquids. Figure 4 shows how the liter compares in size with the dry quart and liquid quart of the English system, one liter corresponding to 0.909 dry quart and 1.057 liquid quarts. The complete table for capacity is given on the following page.

PHYSICS CONCERNED WITH MEASUREMENT

1000 liters = 1 kiloliter (kl.)

100 liters = 1 hectoliter (hl.)

10 liters = 1 decaliter (Dl.)

liter (l.)

.1 liter = 1 deciliter (dl.)

.01 liter = 1 centiliter (cl.)

.001 liter = 1 milliliter (ml.)

The gram—standard unit of mass. The chief unit of mass or weight in the metric system is the gram, which is the exact weight at sea level of a cubic centimeter of water at a temperature of 4° Centigrade. Another important unit is the kilogram, or a thousand grams, which is the exact weight at sea level of a liter of water at 4° Centigrade. As in the case of the meter, the kilogram was fixed

The picture below shows a triple-beam trip balance used in weighing objects by the metric system. A more sensitive balance is required for very accurate weighing.



LOOKING AT PHYSICS IN RELATION TO LIFE

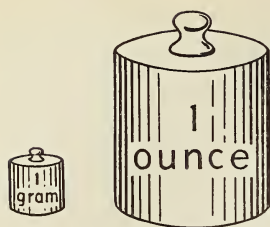


Fig. 5. An ounce is equivalent in weight to 28.4 grams.

arbitrarily, the exact measurement being the weight of a platinum-iridium cylinder preserved in the International Bureau of Standards at Sèvres, France. An exact copy of this cylinder is preserved in the National Bureau of Standards at Washington, D.C. A gram is equivalent to 0.03527 ounce and a kilogram to 2.2 pounds in the English system. Figure 5 enables us to visualize how a gram weight compares in size with an ounce weight. A third unit of importance is the metric ton, which is separate and apart from the table. This unit is the same as 1000 kilograms, and in the English system is equivalent to 2,204.62 pounds avoirdupois. The complete table of the units of mass is as follows:

1000 grams	= 1 kilogram (kg.)
100 grams	= 1 hectogram (hg.)
10 grams	= 1 decagram (Dg.)
	gram (g.)
.1 gram	= 1 decigram (dg.)
.01 gram	= 1 centigram (cg.)
.001 gram	= 1 milligram (mg.)

The second—standard unit of time. The chief unit of time in the metric system is the second, with which we are thoroughly familiar. All the units in the metric system of measuring time are exactly the same as those in the English system. The units in this instance build irregularly rather than in multiples of 10, except the lower units, which build up in multiples of 60. The complete table of the units of time, as we shall use it in the study of physics, is as follows:

7 days	= 1 week (wk.)
24 hours	= 1 day
60 minutes	= 1 hour (hr.)
60 seconds	= 1 minute (min.)
	second (sec.)

PHYSICS CONCERNED WITH MEASUREMENT

ANSWER THESE QUESTIONS

1. Why is the English system of measurement cumbersome?
2. Why is the metric system especially easy to use?
3. What units in the metric system are used for measuring length?
4. How are the units of length transformed into units for measuring areas and cubical contents?
5. What units in the metric system are used for measuring capacity?
6. What units are used for measuring mass or weight in the metric system?
7. How does the table for measuring time in the metric system differ from other tables in the system?
8. What is the equivalent in the English system of each of the following units in the metric system: meter? liter? gram? kilogram? metric ton? second? How many centimeters in one inch?

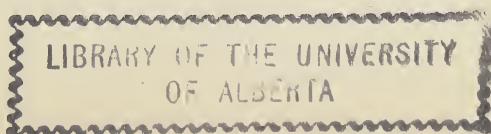
SOLVE THESE PROBLEMS

A

1. Change a kilometer to meters; a meter to centimeters; a centimeter to millimeters; a millimeter to centimeters; a centimeter to meters; a meter to kilometers.
2. Change a liter to deciliters; a deciliter to milliliters; a milliliter to liters; a liter to kiloliters.
3. A rectangular plot 5 rd. long and 3 rd. wide requires a new fence. How many meters of fence are needed to inclose the plot?
4. A window is 1.75 meters long and 70 cm. wide. How many square centimeters does the window occupy?
5. A certain grade of sand weighs 3.5 g. per cubic centimeter. How many grams does a cubic meter weigh?
6. An athlete runs a hundred-meter dash. How much farther does he travel in feet than an athlete running a hundred-yard dash?
7. Measure your height in feet and inches. How tall are you in meters and centimeters?
8. Find your weight in pounds and ounces. How much do you weigh in kilograms and grams?

B

9. A bicycle wheel is 71.12 cm. in diameter. How many revolutions does the wheel make in traveling a mile?
10. A wooden beam is 20 cm. wide, 5 meters long, and 12 cm. thick. How many cubic meters does it contain?



LOOKING AT PHYSICS IN RELATION TO LIFE

11. A boy runs 100 yd. in 10 sec. of time. How long would it take him to run 100 meters at the same rate of speed?

12. A long-distance airplane can fly 10,000 mi. without refueling. How many kilometers can it fly?

13. A cylindrical can is 7.5 cm. in diameter and 1 dm. high. How much is its volume in cubic centimeters?

14. A silver half-dollar weighs approximately 12.5 g. when it comes from the mint. What is the weight in kilograms of \$500.00 in half-dollar pieces?

15. How many kilograms in a metric ton? How many pounds in 16 metric tons?

16. A globe is 30 in. in diameter. How many square centimeters on its surface?

17. A bucket 12 in. high is 9 in. in diameter at the bottom and 10.5 in. in diameter at the top. How many liters of water does the bucket contain if it is filled within 2 in. of the top?

18. A sphere with a radius of 20 cm. is completely filled with water. How many liters of water does it contain? How much does the water weigh in kilograms?

SUMMARY

The science of physics includes five important divisions; namely, mechanics, heat, sound, electricity, and light. This science is very closely related to life. First, it contributes the underlying principles of the many machines found in the world and enables man to use these machines successfully. Second, it provides a basis for critical thinking by which man may arrive at safe conclusions. Third, it supplies understandings which help man to maintain good health, to observe safety rules, to visualize certain fields of work, to practice conservation, to purchase goods intelligently, to preserve a sane outlook upon life, to coöperate effectively with other members of society, and thus to perpetuate the American way of life.

Physics in the strict scientific sense deals with energy in relation to matter. Matter is anything that occupies space, whether solid, liquid, or gas. The variety in matter arises from the fact that it is built up of ninety-two elements and numerous combinations of elements. According to modern theory, all matter, re-

gardless of form or kind, is composed of tiny particles known as molecules; the molecules, of smaller particles known as atoms; and the atoms, of still smaller particles known as protons, neutrons, electrons, and positrons. Matter can be changed from one form to another, but it cannot be created or destroyed. The chief properties of matter are volume, mass, weight, impenetrability, inertia, and porosity. Density is weight per unit volume. Energy is the capacity for doing work. The chief forms of energy are mechanical energy, heat, sound, electricity, and light. All energy may be classified into two large groups, potential and kinetic. Energy may be changed from one form to another, but it cannot be created or destroyed.

Physics is concerned with measurement. There are two leading systems of measurement: the English system, which is commonly used in the United States and Great Britain; and the metric system, which is used in most other countries. The English system developed haphazardly far back in history and is cumbersome to use. The metric system, on the other hand, was specially planned with units that build up in multiples of ten, and consequently is very easy to use. Some of the main units in this system are the centimeter and meter, the milliliter and liter, the gram and kilogram, and the second and minute.

Why may the science of physics be said to cover a broad field?

How does Galileo's experiment with falling bodies mark the beginning of critical thinking?

What are the five steps in the complete process of critical thinking?

What are some of the leading inventions in the field of physics that have helped the world to progress?

Why does the scientist believe in the molecular and atomic theories?

What six properties are common to all kinds of matter?

Why is density a sound basis for comparing the weights or masses of objects?

How is energy related to matter?

How does potential energy differ from kinetic energy?

What is the chief advantage of the metric system over the English system?

LOOKING AT PHYSICS IN RELATION TO LIFE

SOLVE THESE PROBLEMS

1. A contractor uses 100 cu. yd. of concrete in building a wall. What is the weight of the wall if the density of the concrete is 185 lb. per cubic foot?
2. Each face of an iron cube is 1.5 meters square. What is its weight in kilograms if its density is 7.4 g. per cubic centimeter?
3. A lead cylinder is 2 cm. in diameter. How long is the cylinder in centimeters if the cylinder weighs 2.5 kg. and the density is 11.3 g. per cubic centimeter?
4. A cylindrical tank is 2 meters in diameter and 8 meters high. How many liters does it hold?
5. A table top is 2 meters 30 cm. long and 1 meter 40 cm. wide. How large is the table top in square meters?
6. A walk is 30 ft. 5 in. long and 3 ft. 7 in. wide. What is the area of the walk in square feet?
7. An athlete runs 100 yd. in 10 sec. during a race. How long would it take him to run 100 meters at the same rate?
8. An automobile wheel, including the tire, is 81.28 cm. in diameter. How many revolutions does the wheel make per mile?
9. The tank in an automobile holds 16 gal. of gasoline. What is its capacity in liters?
10. A flagpole is 40 ft. high. What is the height of the pole in meters?

INVESTIGATIONS

1. Read various articles on critical thinking and discuss with your classmates how such form of thinking may be applied to ordinary problems of life.
2. Gather information about the invention of the steam engine and prepare a report showing where critical thinking was involved.
3. Prepare a chart of important inventions, including those already mentioned and others which have helped the world to progress. Arrange the list in chronological order and include dates or approximate dates.
4. Read further about the molecular and atomic theories and compare your conclusions with those of other members of the class.
5. Gather data on "smashing the atom" and prepare a summary of what experiments have shown to date.
6. Find out how scientists explain various kinds of energy; namely, mechanical, heat, sound, electrical, and light, and prepare a definition of each for class consideration.



This beautiful streamline train, traveling at a rate of seventy-five or more miles an hour, is under complete control because of the efficiency of its compressed-air brakes.

How Man Controls Liquids and Gases

THE FORCE BEHIND THE BRAKES

When we observe modern means of transportation, we are impressed with their sleekness and speed. We hear the blast of a whistle or the honk of a horn, and a streamline train or an automobile rushes past. As these vehicles disappear in the distance, we think of the motors which enable them to travel so rapidly. Other parts, however, which are just as important but which we

UNIT
TWO

HOW MAN CONTROLS LIQUIDS AND GASES

may overlook, are the brakes. Without brakes these vehicles could not run safely, for their speed would be out of control. In fact, without brakes they would have to travel at extremely slow rates if they were to travel at all.

Not only may we overlook the importance of brakes, but we may also fail to consider their interesting construction. Who, for instance, thinks offhand that a liquid is used to help stop automobiles or that air is used to help stop trains? The fact that such things are possible may be attributed to the wonders of science and to the critical thinking of men who apply science to the problems of living.

The principle back of hydraulic brakes such as are used in automobiles has been known for a long, long time. About three hundred years ago a noted French scientist by the name of Pascal discovered that pressure exerted upon liquid in a closed container is transmitted undiminished to all parts of the interior. In other words, force applied to a liquid in a closed container is multiplied many times. On the basis of this principle, modern scientists have developed hydraulic brakes whereby a small force applied to the pedal of an automobile causes the brakes to exert great force upon the brake bands in the wheels. That the brakes are powerful we know from the fact that a fast-moving automobile can be stopped within a very few feet.

The principle back of compressed-air brakes such as are used on railroad trains and large trucks has likewise been known for many, many years. Pressure exerted upon air in a closed container, like pressure exerted upon a liquid, is transmitted to all parts of the interior. On the basis of this principle, modern scientists have developed air brakes, by means of which a small force applied to the controls causes the brakes to exert tremendous force upon the fast-turning wheels. The real inventor of the brakes was an American by the name of George Westinghouse, who studied the problem because of a wreck. Since the time of his invention in 1886, air brakes have been greatly refined so that both fast-going passenger trains and heavily loaded freight trains are now kept under perfect control.

PRESSURE OF LIQUID BECAUSE OF WEIGHT

These are only a few of the many ways in which man controls liquids and gases and puts them to work. As you read the following pages, you will learn of other uses, together with the important principles involved. More specifically, you will consider the following areas of study.

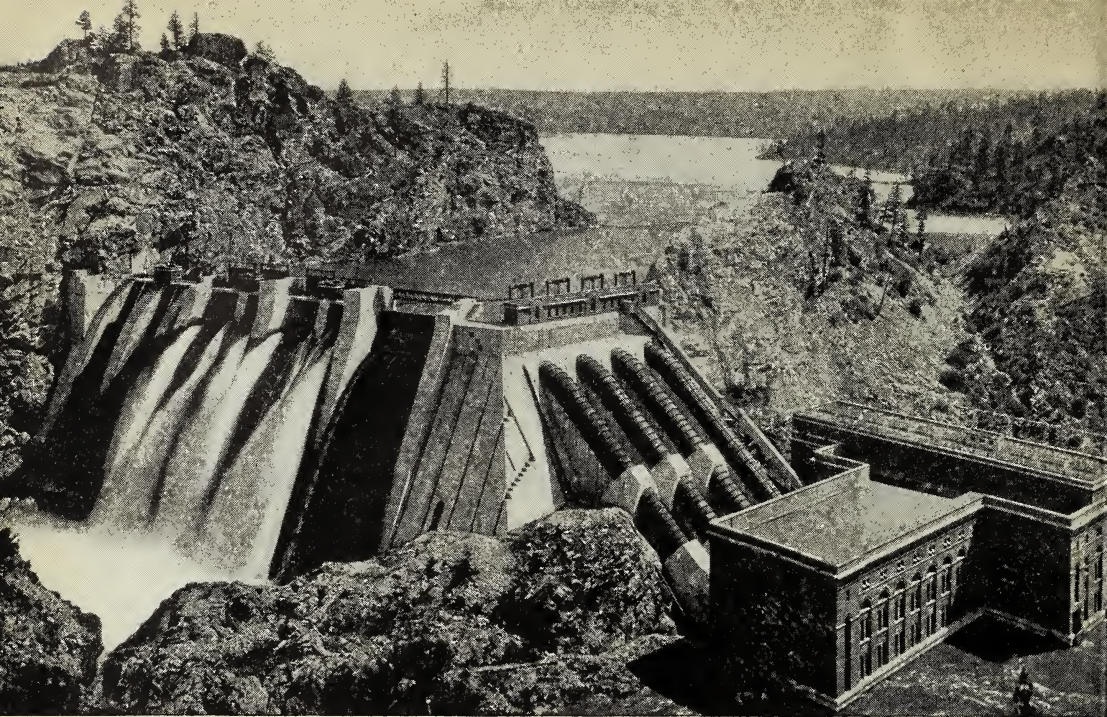
AREAS OF STUDY

- 1. What pressure does a liquid exert because of its own weight?*
- 2. How is a confined liquid affected by pressure?*
- 3. Why do objects appear to lose weight when submerged in a liquid?*
- 4. What pressure does air exert because of its own weight?*
- 5. How does air pressure affect an object in air if the air, the object, or both the air and the object are in motion?*
- 6. How is a confined gas affected by pressure?*

AREA ONE

What Pressure Does a Liquid Exert Because of Its Own Weight?

The behavior of every liquid is affected by its own weight, or the downward pull known as gravity. The weight of a liquid helps to explain why it flows from a higher to a lower level, why it runs out of a hole in a container, why it supports objects lighter than itself, and why it does many other things of importance. All this is of great concern to man, for sometimes the weight of a liquid causes it to work to his advantage and at other times to his disadvantage, depending upon the conditions.



Ewing Galloway

The weight of the water in each of the four conduits acts as a force which turns the blades of turbines for the manufacture of electricity in the building at the right.

Downward pressure of a liquid. The weight of a liquid always acts as a force tending to pull the liquid downward. This is especially noticeable when a liquid is confined in a container, either open or closed, as water in a bucket. If we carry a bucket of water, we can feel the force of the weight acting against our muscles, and if the bucket is fairly well filled we may need to set it down momentarily to rest. The weight of the water in the bucket, of course, acts as a force against the bottom of the vessel, which causes the pull on the handle. *The downward force that a liquid exerts upon any unit area, as a square foot or square centimeter of the bottom of a container, is known as the pressure.* To find the pressure, therefore, we merely divide the total force, or weight, of the liquid by the area of the bottom. In other words, if we let p stand for pressure, F for force, and A for area, we may indicate the computation as follows:

$$\text{Pressure} = \frac{\text{force}}{\text{area}} \text{ or } p = \frac{F}{A}.$$

PRESSURE OF LIQUID BECAUSE OF WEIGHT

Example. A small aquarium 3 feet long, 1 foot wide, and 1 foot high is filled with water. If the total weight of the water is 187.2 pounds, what pressure does the water exert on the bottom?

To solve this problem, we first find the area of the bottom of the aquarium by multiplying the length by the width and thus obtain 3 square feet. Then we substitute 187.2 for F and 3 for A in the foregoing equation, as follows:

$$p = \frac{187.2}{3}.$$

Therefore

$$p = 62.4 \text{ pounds per square foot.}$$

To understand the scientific meaning of pressure in the above problem, let us imagine, as suggested in Figure 6, that the aquarium measuring 3 square feet on the bottom is broken into 3 separate tanks, each of which measures 1 square foot on the bottom. Then each separate tank in the aquarium contains exactly 1 cubic foot of water. The weight of this cubic foot of water, 62.4 pounds, represents the pressure per square foot on the bottom. In the same manner we may think of pressure as the force that a cubic centimeter of water exerts upon a square centimeter of the bottom. This pressure is 1 gram, for a cubic centimeter of water weighs exactly 1 gram.

The definition of pressure, as stated above, is a general definition applying also to the pressure of gases and solids. Let us suppose, in the case of a gas, that the atmosphere, because of its own weight, exerts a force of 132.3 pounds upon a surface three inches square at sea level. Then, if we substitute 132.3 for F and 9 for A in the equation $p = \frac{F}{A}$, we have $p = \frac{132.3}{9} = 14.7$ pounds per square inch. In like manner let us suppose that a solid such as a cubic foot of stone, because of its weight, exerts a force of 300

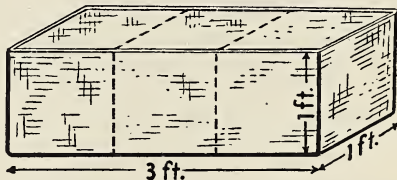


Fig. 6. The above aquarium contains three tanks filled with water.

HOW MAN CONTROLS LIQUIDS AND GASES

pounds upon its base area. If we substitute 300 for F and 144 for A in the equation for pressure, we have $p = \frac{300}{144} = 2.08$ pounds per square inch. Thus we find that, regardless of whether a substance is a solid, a liquid, or a gas, we may find the pressure by dividing the force by the area.

Downward pressure directly proportional to depth and density.

If we place a brick upon a table, the brick exerts a certain pressure upon the table because of its weight. If we place a second brick of the same weight upon the first, the pressure upon the table becomes twice as great; and if we place a third brick upon the second, the pressure becomes three times as great. The same effect may be noted when we increase the depth of liquids in a container. A cubic foot of water in a container, as we have learned, exerts a pressure of 62.4 pounds per square foot against the bottom. If we increase the depth of the water to 2 feet, the pressure against the bottom becomes twice as great, or 124.8 pounds per square foot; and if we increase the depth to 3 feet, the pressure becomes 187.2 pounds per square foot. Likewise, a cubic centimeter of water exerts a pressure of 1 gram per square centimeter against the bottom, but if we increase the depth to 2 centimeters, the pressure against the bottom becomes 2 grams per square centimeter; and if we increase the depth to 3 centimeters, the pressure becomes 3 grams. The pressure increases because we stack up the units of liquid in a column somewhat as shown in Figure 7. Summarizing these observations as a principle, we may say that *the pressure of a liquid against the bottom of a container is directly proportional to its depth.*

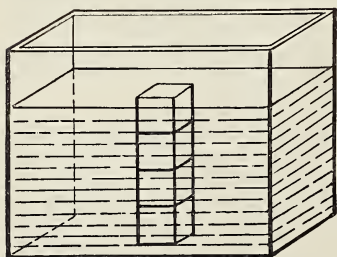


Fig. 7. Imaginary cubic centimeters of water stacked up in a column.

The term *proportional*, as used in the above principle, means *in the same ratio*. The scientist frequently uses this term in comparing quantities, sometimes using the expression *directly*

PRESSURE OF LIQUID BECAUSE OF WEIGHT

proportional and sometimes *inversely proportional*. Two quantities are directly proportional when an increase in one corresponds to an increase in the other, or when a decrease in one corresponds to a decrease in the other. Two quantities are inversely proportional when an increase in one corresponds to a decrease in the other, or a decrease in one corresponds to an increase in the other.

Scientists frequently use graphs to show relationships, such as the relation of the depth of a liquid to its pressure. The graph in Figure 8 shows the relation of the depth of two liquids, gasoline and water, to their pressures. The vertical lines represent height in centimeters, and the horizontal lines, pressure in grams. The large dots represent various heights at which the pressure was recorded during a test. According

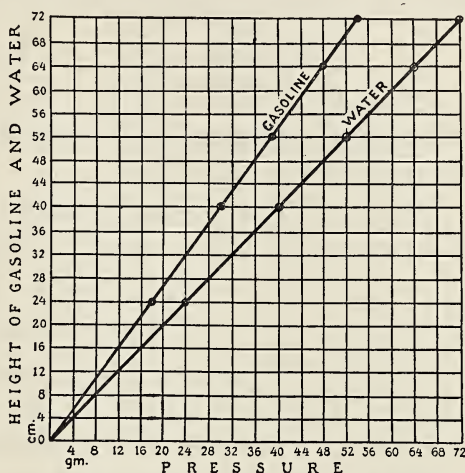


Fig. 8. This graph shows the relation of the depth of water and gasoline to their respective pressures.

to the graph, what is the pressure of gasoline 20 centimeters deep? What is the pressure of water at the same depth? How does the pressure of the two liquids compare at a depth of 40 centimeters? at a depth of 60 centimeters?

Some liquids exert greater pressure than others against the bottom of a container because they have greater density, or weigh more per unit volume. A cubic centimeter of water, for instance, exerts a pressure of 1 gram against a square centimeter of the bottom, but a cubic centimeter of mercury exerts a pressure of 13.6 grams per square centimeter. Whenever we compare the pressure of units of liquids, we really compare the density of the liquids, since density, as we have learned, is mass per unit volume. Accordingly, we may say that *the pressure of a liquid against the bottom of a container is directly proportional to its density*.

HOW MAN CONTROLS LIQUIDS AND GASES

From the foregoing principles we can see that if we know the density of a liquid, or its weight per unit volume, and the depth of the liquid, or the number of unit volumes stacked one above the other, we can readily obtain the pressure against the bottom by multiplying the two. In other words, if we let p stand for pressure, h for height, or depth, and d for density, we may indicate the computation as follows:

$$\text{Pressure} = \text{depth} \times \text{density, or } p = hd.$$

Example. A tank contains 7 feet of water. What is the pressure upon the bottom of the tank if the density of the water is 62.4 pounds per cubic foot?

Solution. To solve this problem, we substitute 7 for h , and 62.4 for d in the above formula, as follows:

$$p = 7 \times 62.4.$$

Therefore $p = 436.8$ pounds per square foot.

Example. The depth of water in a bucket is 20 centimeters. What is the pressure upon the bottom of the bucket if the density of water is 1 gram per cubic centimeter?

Solution. To solve this problem, we substitute 20 for h and 1 for d in the above formula, as follows:

$$p = 20 \times 1.$$

Therefore $p = 20$ grams per square centimeter.

Downward pressure independent of the shape or area of a container.

Offhand we might think that the downward pressure of a liquid is affected by the shape of a container, but investigation shows

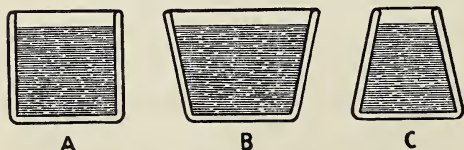


Fig. 9. These containers have the same height and the same base areas but differ in shape. However, the downward pressure is the same in all three.

that such pressure is independent of the shape. For instance, if we look at the vessels in Figure 9, all of which have the same area on the bottom and the same height, we might think that the water in

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vessel B, since this vessel is wider at the top than the others, exerts greater pressure against the bottom than the water in vessels A and C; and we might think that the water in vessel C exerts the least pressure. Strangely, however, the pressure on the bottom of all three vessels is exactly the same. We may prove that this is true by pouring water into a communicating vessel with a variety of upright projections, as shown in Figure 10. If we pour water

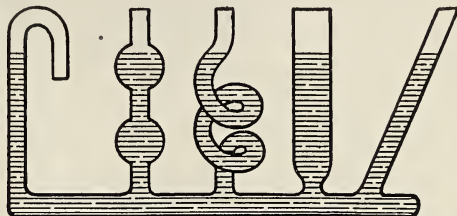


Fig. 10. Water in a communicating vessel rises to the same height in all projections of the vessel.

into one of the projections, we find that it rises to the same height in all the other projections. Therefore the pressure must be the same at the foot of the different projections in the vessel, or the water would stand at different levels rather than seek the same level in all the projections.

Likewise, we might think offhand that downward pressure is affected by the size of a container. Whenever we fill a teakettle, however, the water rises just as high in the spout as in the vessel itself. When an engineer fills the boiler of an engine, the water in the gauge outside rises just as high as the water in the boiler. Therefore we may conclude that downward pressure is not

Water rises in the spout of a teakettle to the same height as in the main part of the vessel. Consequently, when the vessel is filled, water runs out of the spout.

Ferdinand Hirsch





Ferdinand Hirsh

This modern water tower is high enough to provide water for every building in the community. Its operation depends upon the principle of the downward pressure of liquids. Many communities are equipped with water-supply systems such as this.

affected by the size of a container. Summarizing both the foregoing observations, we may say that *the downward pressure of a liquid is independent of both the shape and the size of a container.*

Practical applications of downward pressure. The principles governing the downward pressure of liquids are of great importance to man, especially as applied to water. Many cities, for example, depend upon downward pressure for the operation of their water systems. Such cities always have high reservoirs from which the

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water flows downward, then horizontally, and then upward through pipes to places of use, as shown in Figure 11. The water may be used at various elevations as long as the elevations are no higher than the level of the water in the sources of supply. Many smaller cities and towns have standpipes, and factories and railroads have water towers, from which water flows to lower levels and then to higher places of use. The water in artesian wells and springs also flows from higher sources, through layers of gravel or other soft materials to lower levels from which it rises to outlets above the surface.



Fig. 11. In a water system such as this, which is found in many large cities of the country, the water may be used to a height level with the surface of the water in the reservoir.

One of the most interesting water systems in the country is the Los Angeles system, which depends upon a glacier-fed river high in the Sierra Nevadas, about 250 miles away. The water flows from the mountains to the city through different types of conduits, consisting of cement-lined canals, concrete aqueducts, and large steel pipes. The conduits are extremely large, capable of carrying sufficient water to accommodate the city even though its population should increase several times. Another interesting water system is the New York system, which obtains large quantities of water from the higher Catskill Mountains. This water flows to the city through extremely large tunnels.

The meaning of waterhead. Frequently when scientists consider the downward pressure of water, they refer to the waterhead. The waterhead is a vertical column of water from any point beneath the surface of the water to the plane of the surface. Therefore the waterhead at any faucet or outlet in a water system is the vertical distance between the faucet and the surface of the

HOW MAN CONTROLS LIQUIDS AND GASES

water in the reservoir or tower that supplies the system. If a municipal water system is fed by a reservoir 1000 feet above the city, the waterhead at the ground level of the city is 1000 feet. On the floor of a building 30 feet above the ground level the waterhead is 970 feet, and on a floor 50 feet above the ground level the waterhead is 950 feet. Each foot of water in a waterhead exerts pressure because of its weight, the pressure usually being expressed in pounds per square inch. We can readily calculate this pressure in pounds per square inch by substituting one foot for h and 62.4 pounds (the weight of a cubic foot of water) for d in the equation $p = hd$, and then dividing by 144 (the number of square inches in a square foot), as follows:

$$p = \frac{1 \times 62.4}{144}.$$

Therefore $p = \frac{62.4}{144}$ or 0.433 pounds per square inch.

Having obtained the pressure of one foot of water, we can always obtain the complete pressure of a waterhead by multiplying the pressure of one foot by the total number of feet in the head. Thus if a waterhead is 100 feet we multiply 0.433 by 100 and find the pressure to be 43.3 pounds per square inch. If a waterhead is 1000 feet, we multiply 0.433 by 1000 and find the pressure to be 433 pounds per square inch.

Upward and sidewise pressure of liquids. So far we have considered only the downward pressure of liquids, but liquids also exert pressure in other directions. If we could single out a tiny drop of water anywhere in a bucket of water, for instance, we should find that the pressure upon it is exactly the same from all sides. Otherwise the water in the bucket would move about rather than remain quiet, as it does except when acted upon by an outside force. Even when disturbed, the water becomes stable again as soon as the force ceases to act. From such simple observations as these we may readily conclude that liquids exert pressure upward and sidewise as well as downward.

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We sense the upward pressure of water in a variety of ways, as when we push an empty bucket open end up into a watering trough or barrel. The pressure upward in the water tends to hold the bucket up, and we lower it with difficulty. If we punch a hole in the bottom of an empty can and push it into the water, as shown in Figure 12, we have another manifestation of upward pressure. The water spouts up through the hole, and the farther down we press the can, the higher the water spouts. This happens because the can disturbs the balance that normally exists between the upward and the downward pressures. When we remove the can, the water levels off and the pressure returns to normal.

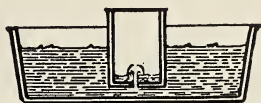


Fig. 12. The water spouts up through the hole in the bottom.

Likewise we have many experiences in which we sense the side-wise pressure in liquids, as when we carry a bucket of water with a hole in the side. If we punch holes in the sides of a tin can and fill the can with water, we have another demonstration of side-wise pressure. The water spouts out of all the holes, but most strongly near the bottom, which shows that the side-wise pressure increases with the depth of the water.

From the foregoing observations we may formulate the principle that *the upward, downward, and sidewise pressures of a liquid at any given point are equal*. We can prove this principle in the labora-

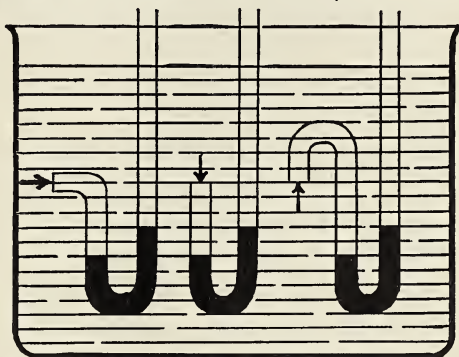


Fig. 13. Regardless of the direction of pressure in the tubes, the mercury stands at the same height.

tory by pouring equal amounts of mercury into three tubes, as shown in Figure 13, and lowering the tubes into water so that all the open ends are on the same level. The first tube then receives the sidewise pressure of the water, the second tube the downward pressure, and the third tube the upward pressure. The

HOW MAN CONTROLS LIQUIDS AND GASES

mercury shows that the pressures are exactly the same, for it stands at the same height in all three tubes.

We may calculate pressure upward, such as the pressure against the bottom of a ship, in the same manner as we calculate pressure against the bottom of a container, through use of the formula

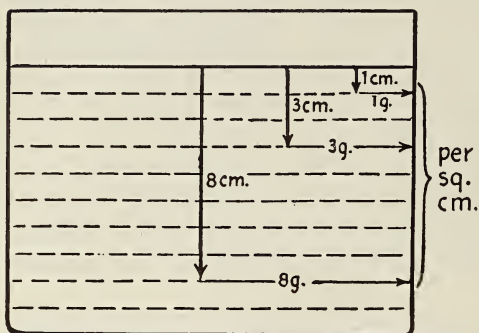


Fig. 14. A diagram showing how the sideways pressure of a liquid varies with the depth of the liquid.

$p = hd$. Likewise, we may calculate pressure sidewise, such as pressure against a dam, through the use of this formula, but in this case we must let h represent the distance from the surface down to the level where we seek the pressure. By looking at Figure 14 we can readily understand why this is necessary. If

the unit of area is one square centimeter, and we wish to determine the pressure against the side just beneath the surface, then h is 1 centimeter. If we wish to determine the pressure against the side 8 centimeters down, then h is 8 centimeters. How much will h be if we wish to determine the pressure against the side at the edge of the bottom?

Example. A rectangular vessel contains 10 cubic centimeters of water. What pressure does the water exert against the side of the vessel 8 centimeters from the surface if the density of water is 1 gram per cubic centimeter?

Solution. To solve this problem, we substitute 8 for h , and 1 for d in the formula $p = hd$, as follows:

$$p = 8 \times 1.$$

Therefore

$$p = 8 \text{ grams per square centimeter.}$$

Practical applications of upward and sidewise pressure. Like the downward pressure of liquids, upward pressure and the sidewise pressure have great influence upon the world. Were it not for the upward pressure of water, for instance, no ships could



Ferdinand Hirsh

The upward pressure of water explains why this canoe, like every other watercraft, floats rather than sinks. The sides and bottom of the canoe contain wooden reinforcements, known as ribs, which help to offset the crushing effect of the water.

sail the seas and no boats could travel over rivers and lakes. Were it not for the sidewise pressure of water, no water systems could be installed, for the water would not flow horizontally through the pipes. Despite the fact that man derives advantages from these pressures, he must frequently take steps to offset them, as in various types of construction. In building ships and boats, he must make the hulls strong enough to keep the water from crushing the bottoms and sides. In building dams and retaining walls, he must make the structures strong enough to keep the water from breaking through. Usually, in the case of dams, he secures this strength by using an inverted **V**-shaped pattern of construction, thus making the structure strongest where the pressure is greatest. A good illustration of this construction is the Grand Coulee Dam recently built on the Colum-

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Fig. 15.

bia River in the state of Washington. This immense dam, which is the largest in volume in the world, is 30 feet thick at the crest, or top, and 800 feet thick at the base. We may visualize its huge size from the fact that 4,000,000,000 pounds of concrete were required for its completion.

Measuring the pressure of a liquid. The pressure of liquids is commonly measured in the laboratory by means of a device known as an open manometer tube. This device consists of a U-shaped tube open at both ends with one arm shorter than the other, as shown in Figure 15. The tube is partially filled with mercury that stands at the same level in both arms. When the shorter arm of the tube is placed beneath the surface of a liquid such as water, the pressure of the liquid causes the mercury to fall in the shorter arm and to rise in the longer arm. Then, if we measure the difference in the heights of the columns of mercury and substitute known quantities in the equation $p = hd$, we can readily calculate the pressure.

Example. Suppose the shorter arm of a manometer tube is placed in a liquid and the mercury in the longer arm is 10 centimeters higher than the mercury in the shorter arm. What pressure does the liquid exert?

Solution. To solve this problem, we substitute 10 centimeters for h , and 13.6 grams (the density of mercury) for d , in the equation $p = hd$, as follows:

$$p = 10 \times 13.6 \text{ or } 136 \text{ grams} \\ \text{per square centimeter.}$$

Outside the laboratory the pressure of liquids is usually measured by means of an instrument known as a pressure gauge, shown in Figure 16. The most common form of

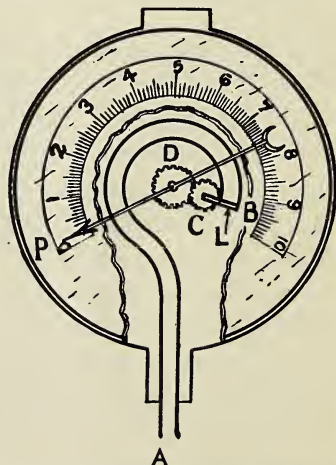


Fig. 16. A Bourdon pressure gauge showing the internal mechanism.

PRESSURE OF LIQUID BECAUSE OF WEIGHT

gauge is the Bourdon gauge, which consists of a circular tube attached to a tank or other closed container at end A and closed, or sealed, at end B. The closed end is attached to cog C, which meshes into cog D and causes it to turn pointer P on the dial, graduated in pounds per square inch. When the gauge is not in use the pointer stands at zero on the scale, but when in use the pressure of the liquid in the container causes the tube to extend slightly and thus through the system of lever and cogs to turn the pointer clockwise. The greater the pressure, the farther the pointer turns on the dial. For example, when the pressure in a city water system is 30 pounds per square inch, the pointer turns farther than when the pressure is 20 pounds per square inch. The Bourdon gauge, as we shall learn later, is also used in measuring the pressure of gases, especially the pressure of steam.

The total force exerted by a liquid because of weight. Frequently we need to consider the total force acting in a liquid, rather than merely the pressure, or force, acting against a unit area. Let us first consider the total force acting against the bottom of a container. Suppose we visualize a column of water 10 centimeters square and 20 centimeters high, as shown in Figure 17. The bottom of such a column, as we can see, has an area of 100 square centimeters, which indicates that the column contains 100 smaller columns of water 1 centimeter square and 20 centimeters high. The pressure of each smaller column against a square centimeter of the bottom is 20 grams, for the density of water is 1 gram per cubic centimeter. Therefore the total force acting against the bottom is 100 times 20 grams, or 2000 grams. If we let F stand for the total force acting against the bottom, A for the total area of the bottom, and p for the

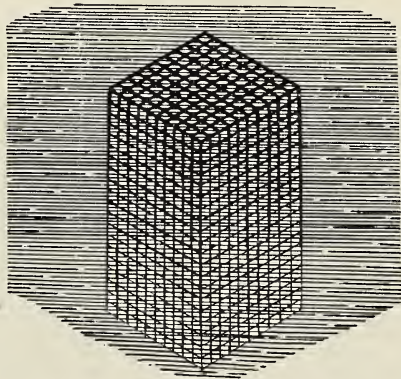


Fig. 17. An imaginary column of water.

HOW MAN CONTROLS LIQUIDS AND GASES

pressure against the bottom, we may write the formula for this computation as follows:

$$F = Ap.$$

We have already learned, however, that pressure, p , is equal to height, h , times density, d , or hd . Therefore we may substitute hd for p in the above formula, revising it as follows:

$$F = Ahd.$$

Example. A rectangular vessel 5 centimeters square on the bottom and 16 centimeters high, is filled with mercury. What is the total force acting against the bottom if the density of mercury is 13.6 grams per cubic centimeter?

Solution. To solve this problem, we first multiply the length by the breadth to obtain the area of the bottom, namely, 25 square centimeters. Then we substitute 25 for A , 16 for h , and 13.6 for d in the foregoing formula, as follows:

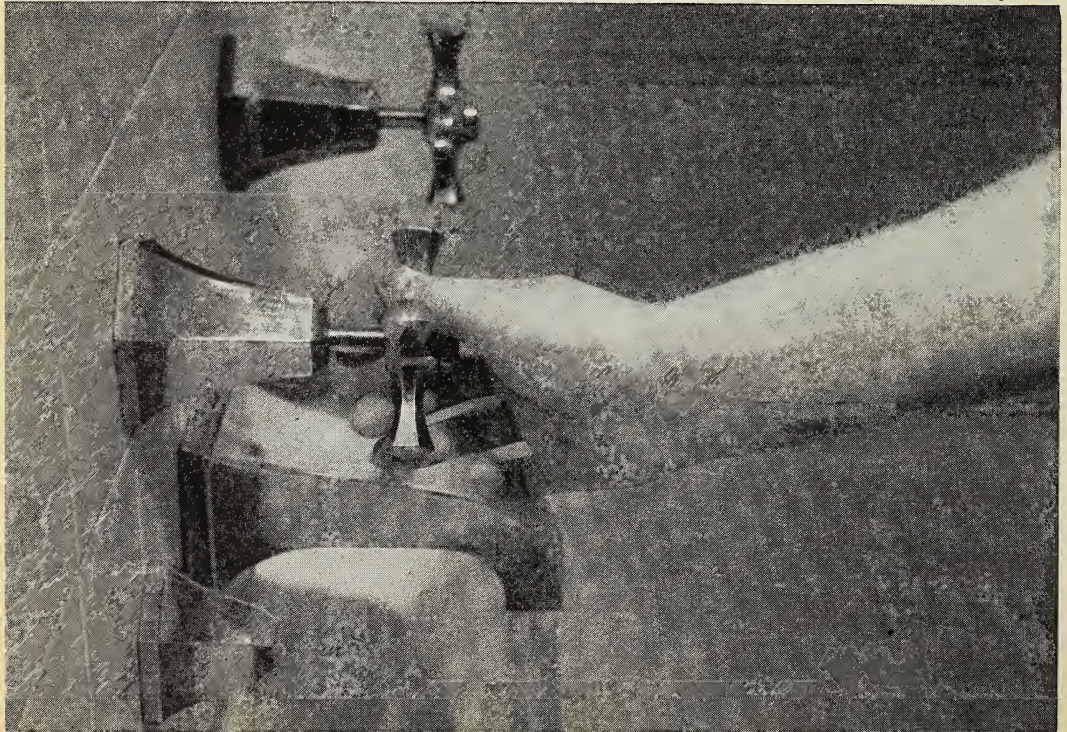
$$F = 25 \times 16 \times 13.6.$$

Therefore

$$F = 5440 \text{ grams.}$$

The force with which the water flows from this faucet depends upon the force exerted upon the water in the system. The force may be exerted either by pumps that pump water into the mains or by the waterhead created by a reservoir or tower.

Ewing Galloway



PRESSURE OF LIQUID BECAUSE OF WEIGHT

Let us next consider the method of calculating the total force of a liquid acting against the side of a rectangular container. We calculate this force in the same manner as above, except that we let h represent one-half the depth of the liquid. We must use h in this way because half the liquid is above the middle of the side and half is below the middle.

Example. Find the total force of mercury acting against one side of the rectangular vessel described in the foregoing problem.

Solution. To solve this problem, we first multiply the height by the width to find the area of one side, namely, 80 square centimeters. Then we substitute 80 for A , one-half 16, or 8, for h , and 13.6 for d in the foregoing formula, as follows:

$$F = 80 \times 8 \times 13.6.$$

Therefore

$$F = 8704 \text{ grams.}$$

ANSWER THESE QUESTIONS

1. What do you understand by the downward pressure of a liquid?

2. How is the downward pressure of a liquid related to the depth of the liquid?

3. How is the downward pressure related to the density of the liquid?

4. What formula may you use in calculating the downward pressure of a liquid?

5. What effect do the shape and area of a container have on the downward pressure of a liquid?

6. How can you prove that a liquid exerts upward and sidewise pressure?

7. How do the upward, downward, and sidewise pressures of a liquid compare?

8. How may you calculate the upward and sidewise pressures of a liquid? What measurement must you use for the height, or h , in calculating sidewise pressure?

9. What formula may you use in calculating the total force acting in a liquid? What measurement must you use for h in calculating the force acting against the side of a container?



Ferdinand Hirsh

This picture shows water towers on the top of a factory. Many tall buildings in cities have water towers to supplement the pressure of the water in the regular water systems.

SOLVE THESE PROBLEMS

A

1. A tank 10 ft. in diameter and 30 ft. high is filled with water. What force acts against the bottom of the tank if the density of the water is 62.4 lb. per cubic foot? What is the pressure per square inch?

2. If a tank 10 ft. long, 8 ft. wide, and 4 ft. deep is filled with water, the density of the water being 62.4 lb. per cubic foot:

- a. What is the total force in pounds acting upon the bottom?
- b. What is the pressure in pounds per square inch acting upon the bottom?
- c. What is the total force in pounds acting upon one side?
- d. What is the average pressure in pounds per square inch acting upon one side?
- e. What is the total force in pounds acting upon one end?
- f. What is the average pressure in pounds per square inch acting upon one end?

PRESSURE UPON A CONFINED LIQUID

3. How high can a pump force water if it exerts a pressure of 100 lb. per square inch?
4. What pressure does sea water exert on the bottom of a ship 30 ft. under water if the density is 64 lb. per cubic foot?
5. A dam is 100 ft. long and 12 ft. high. What force acts against the dam when water reaches the top, if the density of the water is 62.4 lb. per cubic foot?
6. The top of a water tank situated on the top of a building 100 ft. high extends 20 ft. above the roof of the building. When the tank is filled with water, what pressure does the water exert per square inch in the pipe at the base of the building if the density of the water is 62.4 lb. per cubic foot?

B

7. A boy on skates weighs 150 lb., and the area of the skates in contact with the ice is 0.03 square inch. What pressure in pounds per square inch does he exert upon the ice?
8. What is the pressure per square inch one mile below the surface of the ocean if the density of sea water is 64 lb. per cubic foot?
9. How high must the reservoir of a water system be situated above a faucet to produce a pressure of 50 lb. per square inch?
10. A cylindrical tank 40 ft. high is filled with gasoline. What is the pressure in pounds per square inch at the bottom of the tank if the density of gasoline is 0.8 as much as water, the density of water being 62.4 lb. per cubic foot?

AREA TWO

How Is a Confined Liquid Affected by Pressure?

Perhaps we have had the experience of tapping the cork of a jug filled with water and of having the bottom break out. Again, we may have had the experience of putting the cork into a filled thermos bottle and of having a similar accident. After the accident has occurred, we may have wondered how a light force applied to the cork could cause such breakage. The explanation is simple, as we shall find by reading the following paragraphs.

HOW MAN CONTROLS LIQUIDS AND GASES

Great force with little water. The principle of physics which explains these occurrences was first discovered by a French scientist known as Pascal (1623–1662), who performed an experiment with apparatus similar to that shown in



Fig. 18. Pascal's apparatus.

Figure 18. First he filled the barrel part of the apparatus with water, and then poured water into a long tightly fitted pipe on the top of the barrel. As he continued to pour, the weight of the water in the pipe increased, and finally the barrel burst. The bursting took place because the pressure upon the area of the opening where the pipe was attached to the barrel was transmitted undiminished to all equal areas on the inside surfaces of the barrel. If the area of the opening of the barrel was one square inch and the weight of the water in the pipe was five pounds, then the force applied to each square inch of the inside surfaces of the barrel was five pounds. If the area of the bottom inside the barrel was 1000 square inches, then the force applied to the bottom was 1000 multiplied by 5, or 5000 pounds, plus the weight of the water in the barrel. On the basis of this interesting experiment Pascal's law is commonly stated as follows: *Pressure exerted anywhere on a confined liquid is transmitted undiminished throughout the interior of the containing vessel.*

In order to understand Pascal's law as it is commonly applied in everyday use, let us consider the apparatus shown in Figure 19, known as a hydraulic lift. This lift consists of two pistons, one small and one large, operating in the same vessel. The area of the small piston *AB* is one square inch, and the area of the large piston *CD* is 100 square inches. If a force of 10 pounds is applied to the small piston, the resulting force upon the large piston will be 1000 pounds, or 100 times 10. This multiplication of force is due to the behavior of water pressure, indicated by Pascal's law.

Frequently in considering a hydraulic appliance such as a hydraulic lift, we may know the pressure, or force per unit area,

PRESSURE UPON A CONFINED LIQUID

exerted upon one of the pistons and wish to find the pressure exerted upon the other. The pressure upon the small piston may be represented by the formula

$\frac{F}{A}$, in which F represents the force exerted upon the small piston and A represents the area of the small piston. The pressure upon the large piston may be represented by

$\frac{F_1}{A_1}$, in which F_1 represents the force exerted upon the large piston and A_1 represents the area of the large piston. Then according to Pascal's law, since the pressure on equal areas of both pistons is the same, we have the following equation:

$$\frac{F}{A} = \frac{F_1}{A_1}$$

Example. The radius of the small piston of a hydraulic appliance is 2 inches, and the radius of the large piston is 20 inches. If a force of 50 pounds is applied to the small piston, what force is exerted upon the large piston?

Solution. To solve this problem, we first find the area of each piston by applying the rule for finding the area of a circle, namely, by squaring the radius and multiplying by π , or 3.1416. Computing on this basis, we find that the area of the small piston is 12.5664 square inches and the area of the large piston is 1256.64 square inches. Substituting in the foregoing equation, we have:

$$\frac{50}{12.5664} = \frac{F_1}{1256.64}$$

Clearing of fractions
and transposing,

$$12.5664F_1 = 1256.64 \times 50.$$

Therefore

$$F_1 = \frac{62832}{12.5664} \text{ or } 5000 \text{ pounds.}$$

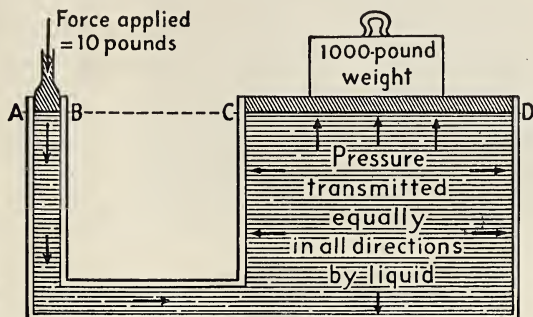


Fig. 19. This hydraulic lift multiplies a 10-pound force by 100, thereby causing it to lift a weight of 1000 pounds.



Pascal
(1623-1662)

Blaise Pascal was a noted French philosopher and mathematician. This early scientist experimented extensively with both liquids and gases and reached many helpful conclusions. One of his findings, which applies specifically to the pressure of confined liquids, is commonly called Pascal's law. Besides exploring various principles of science, he made many contributions to mathematics.

One fact must be remembered about the operation of a hydraulic appliance similar to that in Figure 19, namely, that the force applied to the small cylinder *AB* moves through a much greater distance than the resulting force on the large cylinder *CD*. For example, suppose that we apply a force of 10 pounds to the small cylinder *AB*, which drives the piston downward 10 inches and forces the water into the large cylinder. Since the small cylinder of the appliance has a cross section of one square inch and the large cylinder a cross section of 100 square inches, the water now spreads over a larger area and has less depth. In other words, the force affecting the piston in the large cylinder

CD causes it to rise only $\frac{10}{100}$ or 0.1 inch.

From the foregoing example we observe that the product of the initial force times the distance through which it moves is equal to the product of the resultant force times the distance through which it moves. Accordingly if we let *F* represent the initial force, *d* the distance through which the initial force moves, *F*₁ the resultant force, and *d*₁ the distance through which the resultant force moves, we may express the law in the form of an equation as follows:

$$Fd = F_1d_1.$$

PRESSURE UPON A CONFINED LIQUID

Example. If a force of 100 pounds acts through a distance of 20 inches on the small piston in Figure 19 and lifts a load of 6000 pounds, how far does the large piston move?

Solution. To solve this problem, we substitute 100 for F , 6000 for F_1 , and 20 for d in the foregoing equation, as follows:

$$100 \times 20 = 6000d.$$

Transposing, $6000d = 100 \times 20.$

Therefore $d = \frac{2000}{6000}$ or $\frac{1}{3}$ inch.

Another point which we should remember about the operation of a hydraulic appliance is that the small piston moves much more rapidly than the large piston. This happens because the small piston travels through much greater distance than the large piston. When a machine such as this converts a small force into a large force at the expense of the distance and speed with which the load is moved, the machine is said to have *mechanical advantage*. A full discussion of mechanical advantage will be found later in the book.

Pascal's law applied to everyday life. In everyday life Pascal's law is applied through such devices as the hydraulic jack, the hydraulic press, the city water system, automobile brakes, and airplane brakes. All these appliances have large and small pistons in which small forces applied to the small pistons result in large forces acting upon the large pistons. In the case of the hydraulic jack, such as used at automobile service stations, compressed air acts upon the small piston and causes the large piston to lift an automobile to a height where it can be serviced. In the case of the hydraulic press, such as used in fruit presses, compressed air or other force acts upon the small piston and causes the large piston to squeeze

A barber's chair works in accordance with Pascal's law. The barber raises and lowers the chair by means of the lever at the side.

Ferdinand Hirsh



HOW MAN CONTROLS LIQUIDS AND GASES

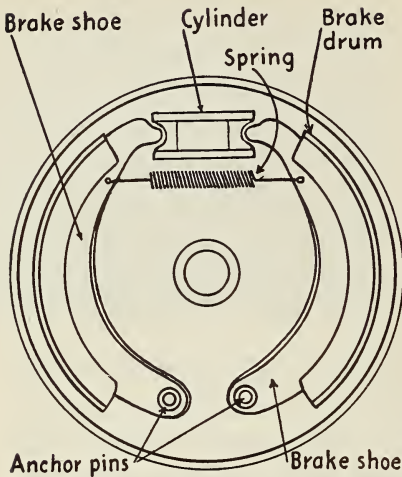


Fig. 20. The hydraulic brake of an automobile showing the placement of essential parts.

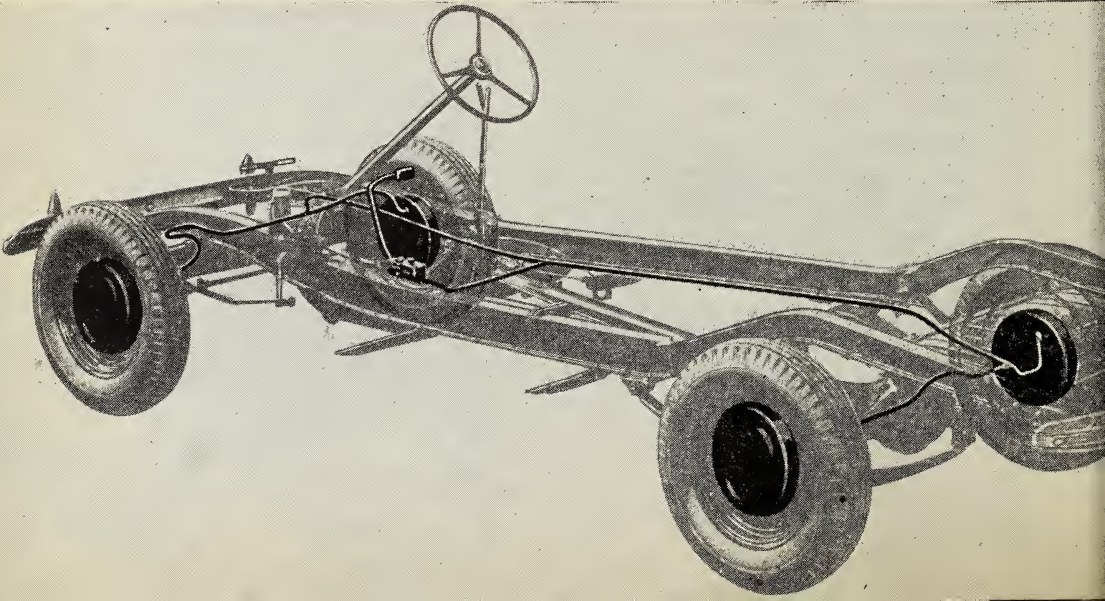
the juice from the fruit. In the case of the city water system a pump at the pumping station applies a small force to the water which causes water to rush from faucets whenever they are turned.

In the case of the hydraulic brakes of an automobile the foot pedal exerts pressure upon the piston of a master cylinder, which is connected by tubes with other cylinders at the wheels. The piston of the master cylinder, acting under pressure from the foot pedal, transmits the force to a liquid that fills the brake sys-

tem and hence exerts pressure upon brake pistons in the cylinders at the wheels. The cylinder at each wheel contains two pistons that move in opposite directions and push outward on the movable ends of brake shoes, as shown in Figure 20, causing them to press against brake drums attached to the frames. When the pressure on the foot pedal is released, a coiled spring pulls the

The darkened part of the picture below shows the hydraulic brake system on an automobile chassis. Through the operation of such a system, the driver, by means of the foot pedal, keeps the automobile under control with surprisingly little effort.

Ferdinand Hirsch



PRESSURE UPON A CONFINED LIQUID

brake shoes away from the drums, forcing the pistons toward the center of the cylinder and the liquid back to the master cylinder. The brakes operate uniformly and exert the same pressure at all the wheels because the master cylinder transmits pressure undiminished in all directions. Under this system a small force applied to the foot pedal exerts a much larger force, uniformly distributed, on the brake drums and thus enables the driver to keep the automobile under control. Such control contributes greatly to safety in driving, especially when an automobile is traveling at a high rate of speed.

In the case of the hydraulic brakes of an airplane, as shown in Figure 21, the system is similar to that of an automobile, except that the brake on each wheel may be operated independently. In other words, the brake on one front wheel attached to the landing gears may be operated without affecting the brake on the other front wheel. The liquid in the hydraulic system is circulated by a power pump, which is driven either by the engines of the airplane or by a special electric motor. The capacity of the pump varies from one and one-half to three gallons per minute, thus creating a maximum working pressure of 1600 pounds per square inch. Provision is made for the use of a hand pump in case the power pump fails to operate satisfactorily. Besides the braking system, each airplane has a separate hydraulic system that controls certain movable parts of the wings in landing, and retracts, or pulls up, the landing gear after taking off in flight. The extensive use of hydraulic pressure for all these purposes has contributed much to safety in flying, its greatest service being in landing and taking off or in taxiing.

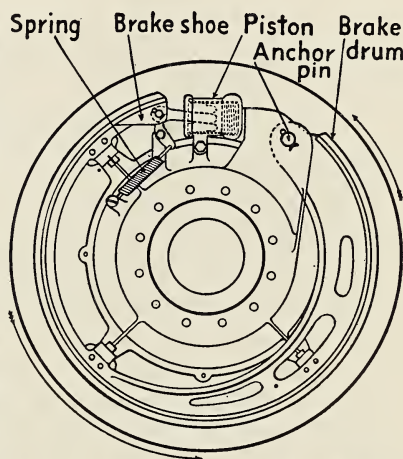


Fig. 21. A single-shoe airplane brake showing the placement of essential parts.

HOW MAN CONTROLS LIQUIDS AND GASES

ANSWER THESE QUESTIONS

1. Why may a person break a filled jug or thermos bottle by tapping lightly on the stopper?
2. What is Pascal's law?
3. How does a force applied to a small piston result in a large force on a large piston operating in the same liquid?
4. How do the distances compare through which the large and small forces operate?
5. How would you explain the operation of a barber's or dentist's chair? the operation of a city water system?
6. How does a small force applied to the foot pedal of an automobile equipped with hydraulic brakes result in large forces acting upon the brake drums of the wheels?
7. How does the airplane depend upon hydraulic systems for safety in landing or taxiing? How do the brakes operate differently from automobile brakes?

SOLVE THESE PROBLEMS

A

1. The diameter of one piston of a hydraulic press is 4 in., and the diameter of the other is 12 inches. If a pressure of 50 lb. is exerted upon the small piston of the press, what force does it exert upon the large piston?
2. The diameter of the small piston of a hydraulic lift is 3 in., and the diameter of the large piston is 15 inches. If a force placed upon the small piston pushes the piston down 6 in., how far does the weight upon the large piston move?
3. If the two pistons of a hydraulic press have diameters in the ratio of 15 to 1, what are the relative areas of the pistons? What are the relative forces exerted upon the pistons? How many times as far does the small piston move as the large one? How much faster does the small piston move?
4. A man who weighs 180 lb. sits in a barber's chair that is raised by hydraulic pressure. If the small piston of the hydraulic system of the chair has a diameter of 2 in. and the large piston a diameter of 8 in., what force in pounds must be applied to the small piston in order to lift the man?
5. The diameter of two pistons of a hydraulic press are 3 in. and 30 in. respectively. How large a weight must be placed upon the small piston to lift a 1000-lb. weight upon the large piston?

OBJECTS SUBMERGED IN A LIQUID

B

6. The diameters of the pistons of a hydraulic jack are 2 cm. and 6 cm. respectively. What force must be applied to the small piston of the hydraulic jack in order to lift a weight of 2000 kg. upon the large piston?

7. What ratio exists between the diameters of the pistons of a hydraulic jack if a force of 50 lb. applied to the small piston lifts a weight of one ton upon the large piston? What ratio exists if 50 lb. lifts a weight of 5 tons?

8. The diameter of the small piston of a hydraulic press in a manufacturing plant is 1 inch. If a force of 20 lb. applied to the small piston lifts a weight of 20,000 lb. upon the large piston, what is the diameter of the large piston?

AREA THREE

Why Do Objects Appear to Lose Weight When Submerged in a Liquid?

Many times we have observed the fact that an object seems lighter when lifted under water than when lifted in air. When swimming, for instance, we lift our arms more easily under water than we lift them in air. If we lift a stone or any other heavy object from the bottom of a swimming hole, we lift it more easily below the surface than above the surface. Likewise, fishermen observe that they lift fish more easily through the water than through the air, provided the fish do not struggle. Such experiences point to an interesting scientific principle which we shall find discussed on the following pages.

The principle of buoyancy discovered. The principle that explains these illustrations, commonly known as *Archimedes' principle*, is one of the few early scientific conclusions accepted by scientists today. This principle, as its name indicates, was devised by the Greek philosopher Archimedes (287–212 B.C.). According to an old story, King Hiero of Syracuse, recognizing the philosopher's

HOW MAN CONTROLS LIQUIDS AND GASES

talents, asked him to determine whether or not the royal crown, which was supposed to be made of pure gold, contained any silver. Archimedes was puzzled for a time, but one day while taking a bath he concluded that his apparent loss of weight was equal to the weight of the water displaced. Then it occurred to him that he might put the crown and equal weights of gold and silver in water, one after another, and compare the volumes of water displaced. If the crown and an equal weight of gold should displace equal quantities of water, he would prove that the crown was made of pure gold. If the crown displaced less water than an equal weight of gold but more than an equal weight of silver, he would know that the crown was alloyed with silver. Dressing hastily and rushing through the streets, he cried, "Eureka! Eureka!" which means, "I have found it! I have found it!"

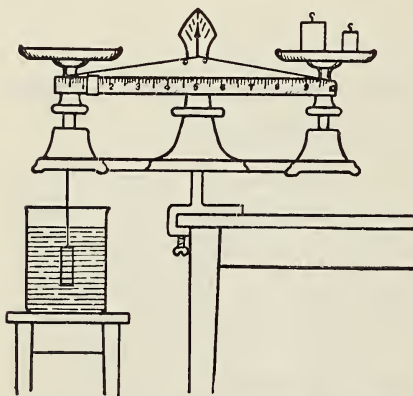


Fig. 22. The cylinder sinks in the water because it weighs more than the water displaced.

The scientific principle that Archimedes discovered is commonly stated as follows: *The buoyant force exerted by a liquid is exactly equal to the weight of the liquid displaced.* According to this principle, if we sink an object in a liquid as shown in Figure 22, we find that the loss of weight of the object is equal to the weight of the liquid displaced. Again, if we float an object in a liquid, we find that the loss of weight of the object,

which in this case is the complete weight, is equal to the weight of the liquid displaced. Thus the law applies both to objects that sink in a liquid and to objects that float.

What is meant by specific gravity? One of the most interesting applications of Archimedes' principle is the manner in which it is used to compare the densities of substances. Density, as we have already learned, is mass per unit volume, the mass being

Archimedes
(287-212 B.C.)

Archimedes was a famous Greek philosopher. Unlike most other thinkers of his time, he believed in experimental evidence rather than conclusions formed by thought processes alone. Consequently he experimented widely and made many contributions to physics. One of his discoveries, known as Archimedes' principle, deals with the apparent loss of weight of objects immersed in a liquid.



expressed in units of weight. In order to compare densities, scientists use certain substances as standards, such as water for liquids and solids and hydrogen for gases. In physics we commonly compare the densities only of liquids and solids for which water is used as the standard. To obtain an index of the density, or weight, of a substance, we compare its weight with the weight of an equal volume of water and assign the substance a ratio. This ratio is commonly known as *specific gravity*, the word *specific* meaning *ratio*, and *gravity*, in this instance, referring to density or weight. Stated technically, *specific gravity is the ratio of the weight of an object in air to the weight of an equal volume of water*. Stated in the form of an equation it appears as follows:

$$\text{Specific gravity} = \frac{\text{weight of body in air}}{\text{weight of equal volume of water}}.$$

On the basis of this equation, if we weigh a cubic centimeter of aluminum in air, we find that it weighs 2.7 grams. Dividing 2.7 by one, the weight of a cubic centimeter of water, we get 2.7, an abstract number representing the ratio of the density of aluminum to the density of water, or the specific gravity of aluminum. Similarly, if we weigh a cubic foot of aluminum, we find that it weighs 168.48 pounds. Dividing 168.48 by 62.4, the weight of a cubic foot of water, we get 2.7 as before. From all this we see

HOW MAN CONTROLS LIQUIDS AND GASES

that, regardless of whether we use the metric system or the English system, the specific gravity is always the same. This is true because the specific gravity is merely a ratio, or an abstract number. In the case of the metric system, it is quantitatively the same as density, because the standard unit, a cubic centimeter of water, weighs exactly one gram. For this reason we must be careful in using the metric system not to confuse the terms *specific gravity* and *density*. The specific gravity of iron, for instance, is 7.86 and the density of iron is 7.86 grams per cubic centimeter, but the two quantities refer to different concepts.

On a similar basis the specific gravity has been determined for all important substances, as listed in the Appendix. Using the specific gravity of any substance, we can always determine its weight by comparing it with the weight of an equal volume of water. For instance, if we have a piece of aluminum five cubic centimeters in size, we know that it weighs 2.7 times as much as an equal volume of water. Since a cubic centimeter of water weighs one gram, five cubic centimeters of water weigh five grams, and the piece of aluminum weighs 2.7 times 5, or 13.5 grams. If we have five cubic feet of aluminum, it weighs 2.7 times 62.4 (the weight of one cubic foot of water), times five, or 842.4 pounds.

Finding the specific gravity of solids. Now let us see exactly how we use Archimedes' principle in finding the specific gravity of substances. First let us apply the principle to solids and consider a solid heavier than water, such as a small cube of iron immersed

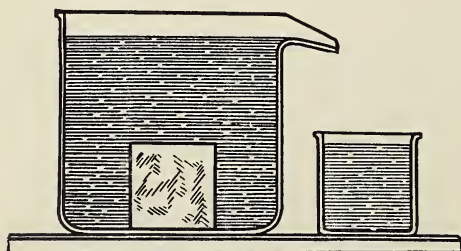


Fig. 23. The cube in the container displaces its own volume of water. Why is this statement true?

in water as shown in Figure 23. The volume of water that overflows in this case exactly equals the volume of the cube because the cube and the water cannot occupy the same space at the same time. The apparent lost of weight of the cube, according to Archi-



The girls in this picture are performing an experiment to determine the specific gravity of a small block of metal. What are the important steps in the experiment?

Archimedes' principle, equals the weight of the water displaced. In other words, the apparent loss of weight is the same as the weight of a volume of water equal to the volume of the cube. Since

$$\text{specific gravity} = \frac{\text{weight of object in air}}{\text{weight of equal volume of water}},$$

then

$$\text{specific gravity} = \frac{\text{weight of object in air}}{\text{loss of weight of object in water}}.$$

Example. An irregular object weighs 120 grams in air and 90 grams in water. What is the specific gravity of the substance?

Solution. To solve this problem, we subtract 90 grams from 120 grams, obtaining 30 grams as the loss of weight of the object

HOW MAN CONTROLS LIQUIDS AND GASES

in water. Then we substitute 120 grams for the weight of the object in air and 30 grams for the loss of weight of the object in water, in the foregoing equation, as follows:

$$\text{Specific gravity} = \frac{120}{30} = 4.$$

In determining the specific gravity of a solid lighter than water, such as a piece of paraffin, we observe the following procedure: First, we weigh the object in air. Second, we attach a sinker to the object and then weigh the sinker under water and the object in air. Third, we weigh the object and the sinker under water. Considering these results, we readily see that, since we have weighed the sinker both times under water, the difference between the second and third weights of the object represents the buoyant effect of the water and hence is equal to the weight of the water displaced. The equation that is used for finding the specific gravity of objects lighter than water is as follows:

$$\begin{aligned}\text{Specific gravity} &= \frac{\text{weight of object in air}}{\text{weight of equal volume of water}} \\ &= \frac{\text{weight of object in air}}{\text{weight of water displaced by object}}.\end{aligned}$$

Example. Find the specific gravity of a block of wood that weighs 40 grams in air. The combined weight of the wood in air and sinker in water is 120 grams, and the combined weight of the wood and sinker submerged is 70 grams.

Solution. To solve this problem, we subtract 70 grams from 120 grams, obtaining 50 grams as the weight of water displaced. Then we substitute 40 grams for the weight of the object in air and 50 grams for the weight of water displaced, in the foregoing equation, as follows:

$$\text{Specific gravity} = \frac{40}{50} = 0.8.$$

If we wish to find the specific gravity of a cylindrical stick which is lighter than water, we simply find the relation between

OBJECTS SUBMERGED IN A LIQUID

the distance the stick sinks and the total length of the stick. Such a method is known as finding specific gravity by flotation, the formula being as follows:

$$\text{Specific gravity} = \frac{\text{distance stick sinks in water}}{\text{length of stick}}.$$

Finding the specific gravity of liquids. There are several methods of finding the specific gravity of liquids, all of which depend directly or indirectly upon Archimedes' principle. Some of the more important methods are described in the following paragraphs:

a. The special-bottle method. In determining the specific gravity of liquids by this method, we use a specific-gravity bottle somewhat like that in Figure 24. First we weigh the empty bottle and then fill the bottle with the liquid under consideration, remove any liquid that overflows and runs down the outside, and weigh again. Subtracting the weight of the empty bottle from the combined weight of the bottle and liquid, we get the weight of the liquid. Next we fill the bottle with distilled water and weigh. (For extremely accurate work we should take into account the temperature of the liquid and water and make corrections for expansion because of changes in temperature.) Subtracting the weight of the empty bottle from the combined weight of the bottle and distilled water, we get the weight of a volume of water equal to the volume of the liquid.

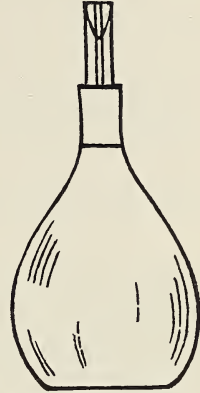


Fig. 24. A specific-gravity bottle.

b. The loss-of-weight method. In determining the specific gravity of liquids by this method, we first weigh a solid in air and then weigh it in water and note the loss of weight, which is the weight of a volume of water equal to the volume of the object. Next we weigh the object in the liquid under consideration and note the loss of weight, which is the weight of a volume of the liquid equal to the volume of the object. Since the same object is used in both cases, the volume of water displaced and

HOW MAN CONTROLS LIQUIDS AND GASES

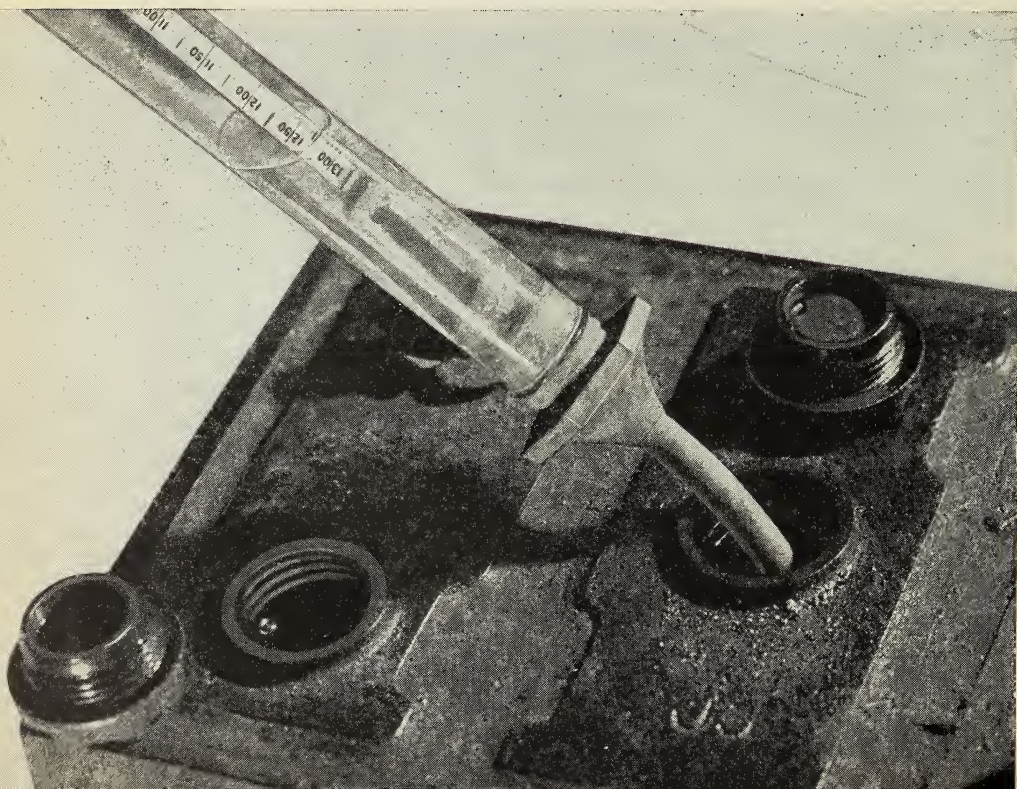
the volume of the liquid displaced are equal. In preparing this test, scientists commonly use a specific-gravity device known as the Westphal balance. This balance, which is an adaptation of an ordinary beam balance, is especially well suited to the purpose: first, because it is extremely accurate; and, second, because it indicates the specific gravity directly, thus eliminating the need of further calculation. The loss-of-weight method is frequently expressed in the form of an equation as follows:

$$\begin{aligned}\text{Specific gravity} &= \frac{\text{weight of object in air}}{\text{weight of equal volume of water}} \\ &= \frac{\text{loss of weight in liquid}}{\text{loss of weight in water}}\end{aligned}$$

c. *The hydrometer method.* In determining the specific gravity of liquids by this method, we use a special instrument known as a hydrometer. This instrument consists of a hollow glass tube with a narrow calibrated stem, sealed and weighted at the lower end so that it stands upright in a liquid. There are two types of

This picture shows how a hydrometer is used in testing the specific gravity of the liquid in a storage battery. Why is it necessary to test a storage battery?

Ferdinand Hirsh



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hydrometers, as shown in Figure 25, the one at the left being suited to liquids lighter than water and the one at the right to liquids heavier than water. One of the most common hydrometers is that used in testing the battery of an automobile. This hydrometer is inclosed in a large glass cylinder with a bulb at the top that enables the user partially to fill the cylinder with liquid, thus allowing the hydrometer to float. The stem of the hydrometer is calibrated to measure the specific gravity of a liquid heavier than water, because the solution of sulfuric acid used in batteries is heavier than water. When a battery is fully charged, the hydrometer reads 1300, which reading means that the liquid has a specific gravity of 1.300. When the charge in the battery is low, the reading is around 1150, which means that the liquid has a specific gravity of 1.150.

Another common form of hydrometer is the lactometer, which is widely used in dairies, creameries, and the like for determining the quality of milk with reference to butterfat. Since butterfat weighs less than skim milk, the greater the butterfat, the less the specific gravity.

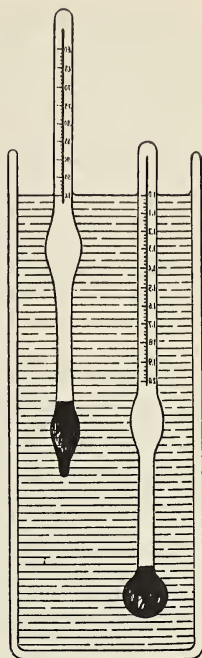


Fig. 25. The two types of hydrometers.

THE MOVEMENT OF SHIPS

Why ships float upon water. From the foregoing study of Archimedes' principle we can readily tell why ships and boats float upon water even though their hulls may be made of iron. A prismatic piece of iron, such as a cube, sinks because it weighs more than the weight of the water displaced, but when the same iron is shaped like a hull it displaces more water and hence weighs less than the weight of the water displaced. Such a hull sinks only until its weight equals the weight of the water displaced, and at this level it continues to float. The size of a ship is always ex-

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pressed in terms of the water displaced. Thus a ship that is listed at 5000 tons displaces 5000 tons of water. Why does a loaded ship displace more water than an empty ship?

Frequently the question arises: How far will a vessel sink in case of shipwreck? The answer is that a ship sinks to the bottom, because water, even at great depths, is only slightly compressed, and a cubic foot of water at the bottom weighs only a little more than a cubic foot of water at the surface. In other words, the density of water changes but little with the depth.

How ships overcome the resistance of water. From what we have already learned about the pressure of water, we can readily understand why water offers resistance to moving objects. The same pressure that causes water to support ships and boats causes it to offer resistance to them as they plow their way along. In order to move, they must split the water and force it out of the way much as a swimmer operates in order to move forward. The fact that all this is true has caused ship and boat builders to give special attention to the shape of the hulls. In general, they have adopted a double-wedge design because this shape has been found best for reducing resistance. Such a shape cuts the water easily at the front, pushes it outward at the sides, and allows it to come together gently in the rear.

Builders are concerned about design, not only from the standpoint of power, but also from the standpoint of speed. The better a ship or boat cuts down the resistance of the water, the less power it requires or the faster it may travel. During recent times, when transportation has been speeded up greatly, most seagoing vessels have been equipped with powerful engines, thus turning the advantage of design in the direction of speed. As a result, ships today travel the sea at much greater speed than ever before in the history of the world. Only four days are required today for the fastest-going ships to cross the Atlantic, whereas Columbus in 1492 required sixty-nine days for the trip.

There is one fact that must be kept in mind in this connection; namely, that when a ship or boat increases its speed it increases

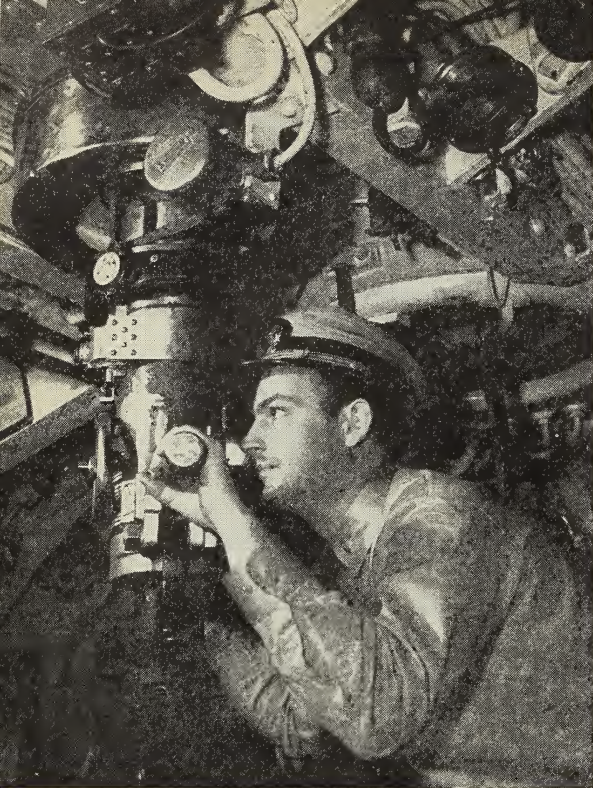
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the resistance of the water because it splits and moves the water aside more rapidly. In fact, at relatively high speeds, if the speed is doubled, the power necessary to drive the vessel because of the increase in resistance must be multiplied by eight. In other words, the power necessary to overcome the resistance is directly proportional to the cube of the velocity. Accordingly, if the speed of a ship is tripled, the power must be increased three times three times three or twenty-seven times. How much must the power be increased if the speed of the ship is quadrupled?

The submarine, a special kind of vessel. The submarine is a special kind of war vessel, so constructed that it may operate either at the surface of the water or beneath the surface. Such a vessel is especially effective because it may attack and retreat while completely submerged and thus remain hidden from the view of surface vessels and airplanes. It is used chiefly for firing torpedoes at enemy ships and for laying mines in enemy waters. In the superstructure of the vessel is a gun that may be used in shelling enemy objectives. Also there may be an airplane or two on the deck for use in reconnoitering activities.

The torpedo, or chief armament of the submarine, is discharged through a tube by the use of compressed air. This armament consists of three main parts; namely, the head, which contains the explosive; the center, which contains the compressed air; and the rear, which contains the propelling apparatus and the directing gears. The propelling apparatus has sufficient power to drive the torpedo more than five miles at a speed of thirty knots. The directing gears keep the torpedo on its course at any desired depth, provided the torpedo is not released too near the surface of the water. The most effective device for combating the submarine is the depth bomb. A depth bomb is a high-explosive shell that sinks to a predetermined depth. Such a bomb may be dropped either by ships or by airplanes whenever there is reason to believe that a submarine is near.

The submarine commonly receives information through its periscope, radio, and sounding devices. The periscope is a long



Ferdinand Hirsh

This man is looking through the periscope at objects, such as enemy ships, on the surface.

projecting tube that transmits scenes on the surface by means of a series of prisms. Usually there are two periscopes, one for observing objects near at hand and one for observing objects some little distance away. The radio is used when the submarine is at or near the surface, but it cannot be used at great depths because the signals are too faint. For communicating at considerable depths, the submarine uses sounding devices that signal directly through the water by means of the Morse code. Such devices receive and transmit messages through a distance of thirty miles or more.

How the submarine is built. The highest part of the submarine is the conning tower, which rises near the middle of the boat and supports the periscope. This tower is made of thick steel plating because it is the last part of the boat to submerge and hence must be strong enough to resist attack from enemy guns. Always at some point on the conning tower is the entrance to the boat, the covering of which is a watertight hinged door known as a hatch. Around the base of the tower is the superstructure, which houses various kinds of equipment such as boats, cables, ropes, and the like.

The hull of the submarine is especially designed to cut down the resistance of the water when the submarine moves forward, and also to withstand the tremendous pressure of the water when the submarine submerges. Consequently the hull usually consists of two parts, an outer hull, which is like a wedge at either end, and an inner hull, which is tubular. When the submarine

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submerges, sea water fills certain chambers between the two hulls and helps to equalize the pressure on both sides of the outer hull. This arrangement is extremely important, for it lessens the strain to which the outer hull is subjected.

The water space between the two hulls is divided into main-ballast tanks and variable-ballast tanks. When the ship operates beneath the surface, the main-ballast tanks are filled, and when it floats, the tanks are emptied. The variable tanks compensate for the variable load on the ship and are filled as necessary to produce the desired buoyancy. The fuel tanks that supply oil for the Diesel engines of the submarine also occupy space between the hulls. The oil moves along under the pressure of water, which is pumped in to take the place of the oil as it is consumed. Such an

The sailors in this picture are occupying stations on the part above the hull of a submarine known as the conning tower. They can come to the outside of the vessel, of course, only when the submarine rests or travels at the surface of the water.

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arrangement is possible because the oil weighs less than water and tends to remain on the surface of the water.

The submarine depends greatly upon compressed air and has three compressed-air systems: a high-pressure system that operates at about 3000 pounds per square inch, a service system that operates at approximately 100 pounds per square inch, and a low-pressure system that operates at 17 pounds per square inch. The high-pressure system is used in blowing water out of the main-ballast tanks, when the ship is about to emerge, and in supplying the service air system through reducing valves. The service air system is used in operating compressed-air machinery, in working flood and vent valves, and in supplying air for breathing. The low-pressure air system is used in blowing water from the ballast tanks when the ship is near the surface.

Attached to the outer hull are an ordinary rudder and two horizontal rudders, one at either end, which are used in helping the ship to rise, to submerge, and to maneuver under water. The horizontal rudders are operated by motors and may be turned as much as 35 degrees in either direction. The rear horizontal rudder has a very wide area that enables it to serve as a fin.

How the submarine rises and sinks. The submarine, as already explained, is so constructed that it rises or sinks in the water. When it rises, its load must be decreased so that its weight, like that of any ordinary ship, equals the weight of the water displaced. When it sinks, its load must be increased so that its weight is greater than the weight of the water displaced. The changes in load are accomplished by the emptying or filling of the main-ballast tanks between the two hulls. Since the volume of water displaced is less when the submarine floats than when it submerges, the volume of the tanks is exactly equal to the volume of the vessel above the surface when the submarine floats. In order to operate efficiently, the submarine must always float at the same level regardless of the weight of its load or the density of the water. To maintain this level the members of the crew empty or fill the variable-ballast tanks as necessary. When the

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submarine rises, certain members of the crew open valves and admit compressed air to the main-ballast tanks, thereby forcing out the water and causing the craft to lose weight. When the submarine dives, these members of the crew open valves and admit water to the main-ballast tanks, thereby causing the craft to gain weight. At the same time they open vent valves to let out the air which otherwise would offer resistance to the incoming water. The ship is assisted in both rising and submerging by the horizontal rudders at either end. The rising or submerging of the submarine may take place very quickly, sometimes in only a fraction of a minute.

How the submarine travels. For traveling at the surface, the submarine depends upon two Diesel engines, each of which may develop as much as 5000 horsepower. The speed may be as high as 25 knots, which is sufficient for the craft to accompany a squadron of battleships at sea. When traveling beneath the surface, the submarine depends upon electric motors, which derive their current from large storage batteries capable of supplying about 1000 horsepower. If the craft merely cruises, the batteries last from 30 to 40 hours, but if it travels at high speed, as indicated above, the batteries last only about two hours. The batteries are charged by the Diesel engines when the craft is floating or traveling at the surface, the motors serving as generators.

ANSWER THESE QUESTIONS

1. What is meant by Archimedes' principle? How did he discover the principle?
2. What is meant by the term "specific gravity"?
3. What is the relation between specific gravity and density?
4. How would you find the specific gravity of a solid heavier than water? of a solid lighter than water?
5. How would you find the specific gravity of a liquid, such as copper-sulfate solution, by the bottle method? by the loss-of-weight method? by the hydrometer method?
6. How is a hydrometer used in measuring the charge of an automobile battery?

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7. What is a lactometer? For what purpose and in what industry is the lactometer used?

8. How does Archimedes' principle help to explain why ships and boats float?

9. Why does water offer resistance to the movement of ships and boats? How do builders seek to overcome resistance through the design of vessels?

10. What relation exists between the resistance of water and the speed at which ships and boats travel?

11. What are the essential parts of a submarine? Why does a submarine have two hulls, an outer hull and an inner hull?

12. How does a submarine rise to the surface? How does it travel beneath the surface?

13. What armaments does a submarine carry?

SOLVE THESE PROBLEMS

A

1. An object weighs 160 lb. in air and 130 lb. in water. What is its specific gravity?

2. A piece of metal 8 cm. long, 3 cm. wide, and 2 cm. thick weighs 360 g. in air. What does the piece of metal weigh when placed under water?

3. A block of stone is 8 ft. long, 4 ft. wide, and 2 ft. thick. How much does the stone weigh if its specific gravity is 7.2?

4. The specific gravity of gold is 19.3. How much does a cubic foot of gold weigh?

5. A swimmer, weight 160 lb., floats in fresh water with only his nose above the surface. What is the volume of his body in cu. ft.?

6. The specific gravity of iron is 7.8. How much force is required to lift a cubic foot of iron under water?

7. What is the weight under water of a cubic foot of each of the following metals: iron (sp. gr. 7.8)? aluminum (sp. gr. 2.7)? lead (sp. gr. 11.4)?

8. A floating stick 10 in. long sinks 8 in. in water. What is the specific gravity of the stick?

9. A stick 10 in. long sinks 8 in. in water and 9 in. in alcohol. What is the specific gravity of the alcohol?

10. A boat displaces 20,000 cu. ft. of water when empty and 30,000 cu. ft. of water when loaded. What weight of cargo is the boat capable of carrying?



Ferdinand Hirsh

Barges, or flatboats as they are often called, such as those in the above picture depend upon Archimedes' principle to enable them to carry coal, petroleum, grain, and other heavy loads. Why do you suppose they are always built wide and flat?

11. A body weighs 400 g. in air, 340 g. in water, and 350 g. in another liquid. (a) What is the specific gravity of the body?
(b) What is the specific gravity of the other liquid?

12. A block of wood weighs 100 g. in air, and a metal ball weighs 100 g. under water. If the block and ball are connected and submerged in water, their total weight is 25 grams. What is the specific gravity of the wood?

B

13. A barge 40 ft. long and 20 ft. wide sinks 24 in. when loaded with coal. How many tons of coal does the barge contain?

14. If a solid with a specific gravity of 7 is dropped into a vessel of mercury with a specific gravity of 13.6, what fractional part of the solid will submerge?

15. If a cylindrical stick 10 in. long sinks 7 in. in water and 8 in. in another liquid, what is the specific gravity of the other liquid? What is the specific gravity of the stick?

16. A piece of lead weighs 4 kg. in air and 3600 g. in sea water with a specific gravity of 1.03. What does the piece of lead weigh in fresh water?

17. An empty bottle weighs 100 grams. When filled with water the bottle weighs 330 g., and when filled with a certain acid it weighs 510 grams. What is the specific gravity of the acid?

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AREA FOUR

What Pressure Does Air Exert Because of Its Own Weight?

At some time in the past we may have heard a radio broadcaster refer to barometric pressure in predicting the weather. For instance, he may have said that the barometric pressure had been falling for the past several hours and that consequently there probably would be a storm. Forecasters always make use of atmospheric pressure in predicting the weather conditions of the immediate future. These predictions are very helpful to certain people such as farmers, fruit growers, airplane pilots, and pilots of ships at sea in carrying on their work.

The discovery that air is matter. People of early times looked upon the atmosphere as a vacuum, or a huge envelope of nothing surrounding the earth. This impression continued until early in the seventeenth century, when the great thinker Galileo performed an experiment proving that air is matter. First he weighed a vessel filled with air at ordinary atmospheric pressure, and then he forced more air into the vessel and weighed it again. Comparing the two weights, he found that the latter was slightly greater than the former. Thus he concluded that air was matter, just as solids and liquids are matter, for only matter could have weight. This discovery was exceedingly important to the world, for it completely changed man's notion of the atmosphere and paved the way for other notable discoveries.

The discovery that air exerts pressure. The first person to continue the study of air after the death of Galileo, about the middle of the seventeenth century, was one of his pupils named Torricelli. This early scientist became interested in the question of what caused water to rise in the stem, or stock, of the ordinary lift pump in use at the time. Finally he attributed the column of water to air pressure on the surface of the water in the well

PRESSURE OF AIR BECAUSE OF WEIGHT

and reasoned as follows: If air exerts pressure and mercury is 13.6 times as heavy as water, air should force a column of mercury about $\frac{1}{13.6}$ times as high as it forces a column of water. Filling a tube about three feet long with mercury, he placed his finger over the open end and inverted the tube into a vessel partially filled with mercury, as shown in Figure 26. Part of the mercury ran into the vessel, but approximately thirty inches, or seventy-six centimeters, remained in the tube, convincing him that the atmosphere exerted sufficient pressure upon the surface of the mercury in the vessel to support the mercury in the tube.

A few years after Torricelli performed this experiment, Pascal became interested in air pressure and carried a mercurial vessel and tube up a high tower. Noting a slight fall in the height of the column of mercury, he asked a relative to carry similar apparatus up a high mountain. This relative noted a decided fall in the height of the column, and from these two experiments Pascal concluded that, upward from sea level, air exerts less and less pressure. Thus he laid the foundation for a method of measuring altitude that is in extensive use today.

A third person who experimented with air pressure was a German scientist named Otto von Guericke. This scientist, who lived at about the same time as Torricelli and Pascal, invented the vacuum pump. With this pump and two small hemispheres, commonly known as Magdeburg hemispheres after the name of his home town, he proceeded to demonstrate the tremendous pressure of air. To one of the hemispheres he attached a stop-cock through which he withdrew the air with his newly constructed vacuum pump. Then he attempted to pull the hemispheres apart and found that they held as if they had been

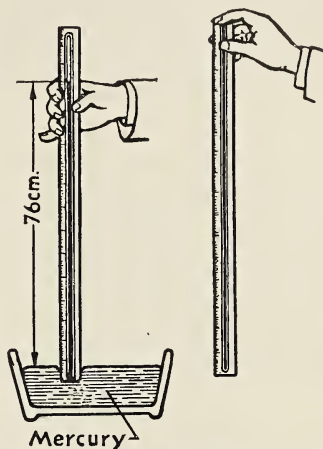


Fig. 26. Torricelli showed that the atmosphere would support a column of mercury 76 centimeters high.

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fastened together. Later he constructed two large hemispheres twenty-two inches in diameter and put on a notable demonstration before the ruler, Emperor Ferdinand III. First he removed the air from the joined hemispheres with a large air pump and then hitched horses, two teams of two horses each, to the hemispheres to pull them apart. Finding two teams insufficient, he kept increasing the number until he had hitched eight teams, four to each hemisphere, before the hemispheres came apart.

How great is air pressure? Now that we have read how early scientists discovered air pressure, let us consider how great this pressure is under normal conditions. In performing his experiment with the mercurial vessel and tube, Torricelli found that the atmospheric pressure upon the surface of the mercury in the vessel supported a column of mercury 76 centimeters, or about 30 inches, high in the tube. Nobody knows how large a tube

This boy is attempting to pull apart two Magdeburg hemispheres from which he has exhausted the air by means of a vacuum pump. The apparatus at the left shows what the hemispheres will be like when he has completed the experiment.



PRESSURE OF AIR BECAUSE OF WEIGHT

Torricelli used in the experiment nor does it matter, for the size of the tube has no relation to the height of the column. For purposes of calculation, let us suppose that the tube had a cross section of one square centimeter. Then the air pressure upon the mercury in the vessel supported a column of mercury one square centimeter in cross section and 76 centimeters high. Earlier in the unit, when considering the pressure of liquids, we used the following equation, which applies equally well to the pressure of gases, namely:

$$p = hd.$$

If we apply this equation to the situation just described, p represents the air pressure in grams per square centimeter upon the surface of the mercury in the vessel, h represents the height of the column of mercury in the tube, or 76 centimeters, and d represents the density of mercury, or 13.6 grams per cubic centimeter (the specific gravity of mercury being 13.6). Substituting these quantities in the equation, we have the following:

$$p = 76 \times 13.6, \text{ or } 1033.6 \text{ grams per square centimeter.}$$

Next let us suppose that the cross section of Torricelli's tube was one square foot rather than one square centimeter and that we hold to the English system of measurement. The air pressure upon the mercury in the vessel, in this instance, supported a column of mercury one square foot in cross section and 30 inches, or two and one-half feet, high. The density of water, as we have already learned, is 62.4 pounds per cubic foot. Since the specific gravity of mercury is 13.6, the density of mercury is 13.6 times 62.4 pounds, or 848.6 pounds, per cubic foot. Substituting in the foregoing equation, we have

$$p = 2.5 \times 848.6, \text{ or } 2121.5 \text{ pounds per square foot.}$$

If we wish to find the pressure of air per square inch, we merely divide 2121.5, the pressure per square foot, by 144, the number of square inches in one square foot. Thus we find that the pressure of air per square inch is 14.7 pounds.

HOW MAN CONTROLS LIQUIDS AND GASES

The mercurial barometer. Atmospheric pressure today is measured by means of an instrument known as the mercurial barometer, which is patterned somewhat after the apparatus used by Tor-

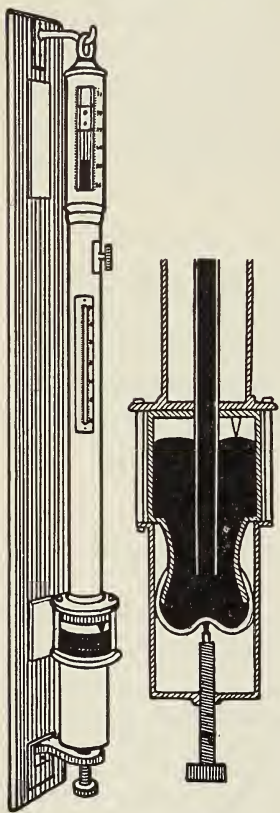


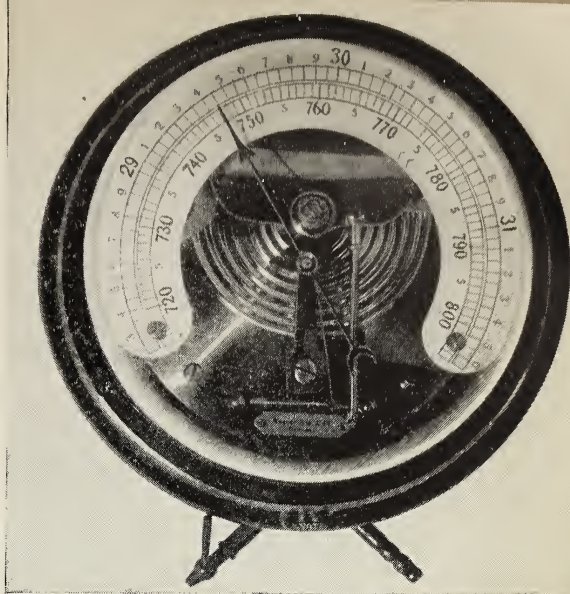
Fig. 27. A mercurial barometer and the mechanism for adjusting the barometer.

ricelli. This instrument, as shown in Figure 27, consists of a tube and bowl attached to a board that serves as support for hanging the instrument on a wall. The tube and bowl are partially filled with mercury, and a scale attached to the board enables a person to read the height of the mercury column in the tube. At the bottom of the instrument is a thumbscrew that enables the reader to adjust the level of the mercury in the bowl until it barely touches the tip of an ivory peg, the zero point on the scale. When the pressure upon the mercury in the bowl increases, the mercury rises in the tube, and when the pressure decreases, the mercury falls in the tube.

Under ordinary conditions the barometric reading at sea level is accepted as 76 centimeters, or 30 inches. In 1939, however, the United States Weather Bureau and the United States Navy further refined this measure by adopting a new unit known as the bar, which under normal conditions represents 29.53 inches at sea level. The bar is divided into 1000 equal parts known as millibars, abbreviated *mb*. In order to record the pressure in millibars, a person must divide 1000 by 29.53 and multiply the quotient by the number of inches of mercury.

The aneroid barometer. The mercurial barometer is an accurate measure of air pressure, but it is difficult to move about because of its bulk and the danger of spilling the mercury. Conse-

quently, for field work, scientists commonly use an instrument known as the aneroid barometer. This instrument consists of an airtight metal box shaped somewhat like an alarm clock. The air has been partially exhausted from the box, and at the top is a sheet of elastic metal that pushes in or out as the atmospheric pressure increases or decreases. The metal sheet is attached to a system of levers that operate a pointer on a dial, the dial being calibrated in centi-



The aneroid barometer, which looks somewhat like an alarm clock, is a sensitive instrument convenient to carry from place to place.

meters or inches as on a mercurial barometer. In order to read the barometer, a person merely observes the number at the end of the pointer on the dial. In general, this barometer is very sensitive, frequently indicating a difference in pressure even between two consecutive floors of a building.

Since the aneroid barometer is especially convenient in field work, it has been widely used in determining the relation between air pressure and altitude. Men have carried it up high mountains, taken it up in airplanes, and sent a self-registering type up in balloons twenty miles or more. From these investigations they have found that the relationship between air pressure and depth differs from the relationship between water and depth. Water pressure, as we recall, is directly proportionate to the depth because the density of water varies but little with depth. Air, however, is highly compressible, and consequently the relation between pressure and depth follows no such uniform pattern. Near sea level, for instance, the barometer reading drops nine-tenths centimeter in a rise of 100 meters, whereas at a height of 2000 meters it drops only seven-tenths centimeter in a rise of 100 meters. Nobody knows exactly how high the atmosphere extends, but from observations of high clouds, meteors, and the

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aurora borealis, or northern lights, scientists are certain that it extends at least 300 miles. Figure 28 shows the effect of changes of altitude upon air pressure as indicated by an aneroid barometer when the barometer is carried upward from sea level.

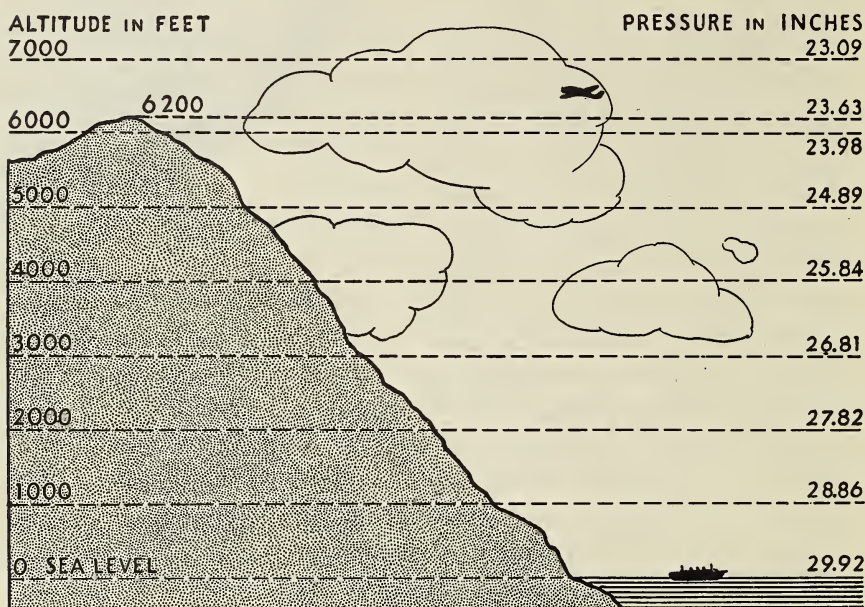


Fig. 28. The above diagram shows the relation of air pressure to altitude. According to the diagram, what readings would you observe on a barometer at various heights above sea level?

The barometer as an index of weather. Besides being helpful in measuring altitude, the barometer also serves as an index of weather. Most of the storms in our country occur because of the formation of great whirls in the atmosphere where warm air currents from the south meet cold air currents from the north. These whirls, which may be as much as a thousand miles in diameter, usually form in the western part of the country and move in an easterly direction, veering to the south and occasionally to the north. Each eddy surrounds a great area of low pressure that causes the eddy to be known as a "low" and that may be visited by rainfall, thunderstorms, or even tornadoes.



U. S. Weather Bureau

A tornado, such as illustrated in the picture above, is hard to predict, but the atmospheric disturbances preceding a tornado reveal when such a storm is probable.

A low is usually followed across the country by another great whirl in which the conditions are reversed. Instead of surrounding an area of low pressure the whirl surrounds an area of high pressure, and instead of being accompanied by stormy weather it is accompanied by clear weather. This whirl, because it surrounds an area of high pressure rather than an area of low pressure, is commonly known as a "high."

Through barometric readings the United States Weather Bureau studies the location and movements of highs and lows throughout the country. It places this information on maps, showing just where various whirls are and in which direction they are traveling. On the basis of these data it predicts the weather for the immediate future, indicating whether it will be clear or stormy. Usually the predictions are very reliable; but occasionally a whirl fades out before it reaches a region or it changes its course, sometimes veering to the north and at other times to the south. In such cases we should not blame the weatherman for his errors, because he cannot be held accountable for conditions beyond his control.

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The buoyancy of air. Earlier in this unit we learned that when a body is submerged in a liquid such as water, it is buoyed up by a force equal to the weight of the liquid displaced. Likewise, when a body is submerged in a gas such as air, it is buoyed up by the weight of the gas displaced. We can readily see that this is true by performing an experiment with objects of equal weight but of unequal size. First we balance the objects from a sensitive lever in air, as shown at the right in Figure 29, and then place the equipment under a bell jar as shown at the left and exhaust the

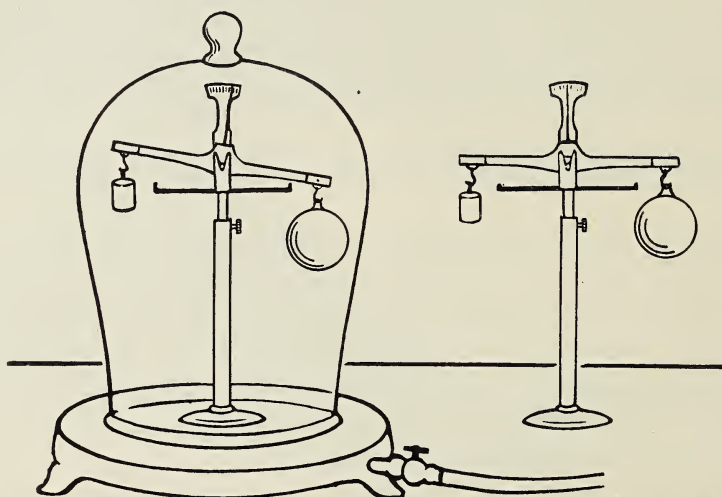


Fig. 29. These drawings show apparatus for measuring the buoyancy of air. The drawing at the right shows a ball balanced by a weight in the air. The drawing at the left shows how the ball drops when the apparatus is placed in a vacuum.

air with a vacuum pump. The larger object now pulls the lever downward, showing that it weighs more than the smaller object in the vacuum. From this finding we may conclude that when the objects were balanced in air, both objects were buoyed up, but the larger object, occupying more space than the smaller object, was buoyed up more than the smaller object.

In the case of most objects the weight of displaced air and the corresponding loss of weight are almost negligible, but in the case

PRESSURE OF AIR BECAUSE OF WEIGHT

of a few objects, such as the balloon, it is readily observable. The balloon, as we doubtless know, is always filled with a gas, such as hydrogen, that is lighter than air. The difference between the weight of the displaced air and the weight of the hydrogen causes the balloon to rise. For purposes of illustration let us suppose that a balloon, when completely filled with hydrogen, occupies 1000 cubic feet of space. A cubic foot of hydrogen weighs approximately 0.005 pound. Therefore the total weight of the gas in the balloon is 5 pounds. A cubic foot of air, on the other hand, weighs approximately 0.08 pound under normal conditions, so the displaced air weighs 80 pounds. The difference between 80 pounds and 5 pounds, or 75 pounds, less the weight of the materials from which the balloon is constructed, represents the buoyancy that causes the balloon to rise. Since the density of the atmosphere decreases with altitude, the balloon rises only to a level where the weight of the displaced air exactly equals the weight of the hydrogen plus the weight of the materials of which the balloon is composed.

The balloon has been used extensively in recent years for different kinds of observation at different altitudes. The weather bureau has been able to measure temperature and atmospheric pressure by using the balloon to carry sensitive instruments into the air. The quantity of gas in the balloon determines the height to which it can be made to rise. The armed forces of the United States have used balloons for the purpose of observing large-scale operations of troops in practice maneuvers. All of these activities are made possible by the buoyancy of the air and the fact that air supports an object in proportion to its weight.

An interesting modification of the balloon is the dirigible, which, like the balloon, is filled with a light gas but is also supplied with motors and propellers. The difference between the weight of the displaced air and the gas enables the craft to rise, and the motors and propellers enable it to move buoyantly. The gas is usually a kind known as helium, which is extremely light and is noninflammable. Since the dirigible is large and clumsy, it is less serviceable than the airplane and less widely used.

HOW MAN CONTROLS LIQUIDS AND GASES

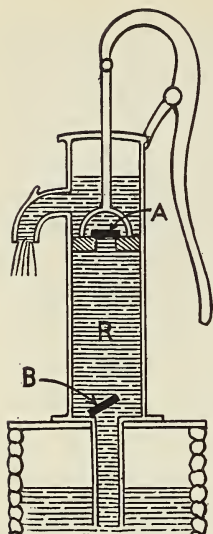


Fig. 30. Diagram of an ordinary lift pump.

The lift, or suction, pump. One of the most common devices depending upon air pressure is the ordinary lift, or suction, pump used in many wells and cisterns. The atmospheric pressure upon the water in a well causes the water to rise in the stem, or stock, of the pump much as atmospheric pressure upon a liquid in a glass causes it to rise when we drink from a straw. Now let us examine a lift pump, as illustrated in Figure 30, to see exactly what happens as the pump is used. When we push down on the handle of the pump, we raise the piston and close valve *A*, causing a partial vacuum in chamber *R*. At the same time the air pressure upon the water in the well pushes water up the stock past valve *B*. When we raise the handle, we lower the piston and close valve *B*, thus trapping the water in chamber *R*, but valve *A* opens and allows the water to pass through the piston. Then, when we lower the handle again, we raise the piston, closing valve *A*, and lift the column of water above the piston sufficiently for some of it to run out of the spout. A lift pump works only when the distance between the lower valve and the level of the water in the well is 34 feet or less, because atmospheric pressure supports a column of water only 34 feet high at sea level.

The force pump. A second kind of pump that depends upon air pressure is the ordinary force pump, which is similar to the lift pump except that it has no valve in the piston, as shown in Figure 31. When we push down the handle of such a pump,

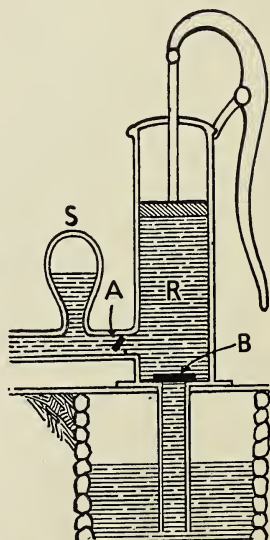


Fig. 31. Diagram of a force pump with essential parts.

PRESSURE OF AIR BECAUSE OF WEIGHT

we raise the piston and create a partial vacuum in chamber *R*. At the same time the air pressure upon the water in the well pushes the water up the stock past valve *B*, thus filling chamber *R*. When we raise the handle, we lower the piston, close valve *B*, and force the water through valve *A* into the spout. To secure a continuous flow of water, an air chamber *S* is placed in the spout. Then when the piston moves downward and forces water into chamber *S*, it compresses the air in chamber *S*. This compressed air forces the water from chamber *S* on through the outlet in a continuous stream. As in the case of the lift pump, a force pump works only when the distance between the lower valve and the level of the water in the well is 34 feet or less. It has a distinct advantage over the lift pump, however, since it forces water to any desired height. For this reason, it is commonly used on fire engines to throw water upon burning buildings.

The siphon. Another common device depending upon air pressure is the siphon, a bent tube with arms of unequal length used in transferring liquids over small elevations from higher to lower levels. If we fill a siphon with water, as shown in Figure 32, and place the shorter arm in the higher vessel *A*, which contains water, and place the longer arm in the lower vessel *B*, water begins to flow through the tube from vessel *A* to vessel *B*. The force that causes the water to flow is the difference in the weights of the columns of water in the two arms. If *rs* represents the weight of the column of water in the short arm and *mn* the weight of the column in the long arm, and *mt*, a part of *mn*, exactly equals *rs*, then *tn* represents the difference in weight of the column of water in the two arms. This difference, or the weight of the

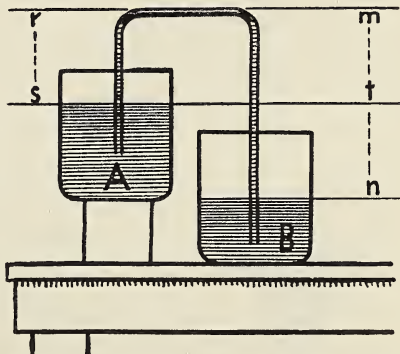


Fig. 32. This siphon, which is merely a bent glass tube, transfers water from the higher vessel indicated by *A* to the lower vessel *B*.



Frequently when a sediment settles in a liquid, as shown above in the vessel at the left, a scientist uses a siphon to remove the liquid without disturbing the sediment. Armbrust

column of water tn , produces the force that causes the water to flow. If we raise vessel B until the surface of the water is as high as the surface of the water in vessel A , the column of water tn disappears and the water ceases to flow. If we raise vessel B so that the surface of the water is higher than the surface of the water in vessel A , the water flows in the opposite direction. At sea level, since air pressure supports a column of water 34 feet high, the siphon works only when the short arm rs is less than 34 feet long. At higher altitudes, since the air pressure is less than at sea level, the arm must be shorter still.

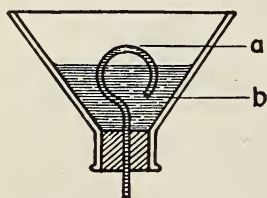


Fig. 33. A diagram of an ordinary intermittent siphon.

Another type of siphon that is widely used is the intermittent siphon shown in Figure 33. When the vessel surrounding the siphon is filled with a liquid to level a , the liquid begins to flow and continues to flow until it falls to level b . Before the siphon will work anew the vessel must be filled again to level a .

PRESSURE OF AIR BECAUSE OF WEIGHT

ANSWER THESE QUESTIONS

1. How did people regard the atmosphere in early times?
2. How did Galileo prove that air is matter?
3. How did Torricelli prove that air exerts pressure? How did Pascal prove that the pressure of air decreased upward from sea level?
4. What interesting experiment did Von Guericke perform to show the tremendous pressure of air?
5. How high a column of mercury measured in centimeters will the atmosphere support at sea level? How high a column measured in inches will it support?
6. How does a mercurial barometer measure the pressure of atmosphere? What are millibars of pressure?
7. How does an aneroid barometer measure the pressure of atmosphere? What advantage has it over the mercurial barometer? Why is it widely used in measuring altitude?
8. How does the barometer serve as an index of weather?
9. How does a lift pump work? Why must the lower valve in such a pump be within 34 ft. of the surface of the water in the well?
10. If two objects of equal weight but unequal size are suspended in air, on which does the air exert the greater buoyancy?
11. What determines the height to which a balloon can rise?
12. How does a force pump work? Why will it force water to any desired place or height?
13. How does a siphon operate? For what purposes is a siphon used?

SOLVE THESE PROBLEMS

A

1. If the air pressure is 14.7 lb. per square inch, how high a column of mercury measured in inches will it support? How high a column of water measured in feet will it support?
2. How would the height of the mercury be affected, if at all, if the diameter of the column were doubled?
3. What is the atmospheric pressure in pounds per square inch if the reading on a mercurial barometer is 30 inches?
4. What is the atmospheric pressure in grams per square centimeter if the reading on a mercurial barometer is 74 centimeters?

HOW MAN CONTROLS LIQUIDS AND GASES

5. The famous Magdeburg hemispheres were 22 in. in diameter. How much force was required in pounds to pull them apart under normal atmospheric pressure?

6. If a diving bell, or caisson, is placed 6 ft. beneath the surface of the water, how much air pressure in pounds per square foot must it have within in order to keep the water from entering?

7. What pressure in pounds per square inch must a force pump exert in order to throw water 85 ft. high?

B

8. If a barometer reads 30.1 in. at the foot of a cliff and 29.2 in. at the top of the cliff, how many feet high is the cliff?

9. If the specific gravity of gasoline is 0.75, over how high an elevation can it be siphoned?

10. How many pounds of air at ordinary pressure are there in a room 30 ft. long, 20 ft. wide, and 10 ft. high?

11. A balloon that occupies 40,000 cu. ft. of space and weighs 1000 lb. is inflated with 150 lb. of hydrogen. What is the lifting force of the balloon if the density of air is 0.072 lb. per cubic foot?

12. An aneroid barometer is carried to a certain height on the slope of a mountain. If the reading of the barometer falls 0.75 in., what is the difference between the two elevations?

AREA FIVE

How Does Air Pressure Affect an Object in Air If the Air, the Object, or Both the Air and the Object Are in Motion?

In our discussion of air pressure so far we have considered only the pressure of air at rest in relation to an object at rest. Frequently in everyday life, however, we are concerned with air in motion in relation to an object, an object in motion in relation to air, or both air and an object in motion. One of the best examples in this connection may be found in the field of transportation in the movement in relation to air of fast-going conveyances, such as automobiles, railroad trains, and airplanes.

AIR PRESSURE IN RELATION TO MOTION

AIR PRESSURE AND TRANSPORTATION

Streamlining the automobile and railroad train. Earlier we learned how the pressure of water causes ships to meet resistance in travel and how designers seek to lessen the resistance by building double, wedge-shaped hulls. Similarly, the pressure of air causes automobiles and railroad trains to meet resistance in travel. This happens because air, like water, has inertia and occupies space, and hence must be split and pushed aside. The resistance that any moving object encounters in air because of air pressure is commonly known as air resistance.

When travel was comparatively slow, air resistance provided little difficulty, and slight attention was given to design, except for purposes of appearance. The radiators and windshields of automobiles were made practically flat in front, and likewise the boilers and cabs of locomotives. Gradually, however, the rate of speed increased, and air resistance became an important problem. Then manufacturers began to give serious consideration to streamlining, to sloping and rounding the parts in such a way as to reduce air resistance to a minimum. Consequently all automobiles and fast-moving trains today are specially shaped to enable them to split and push aside the air with maximum efficiency. Streamlining has an important effect, not only upon speed, but also upon the amount of power that must be supplied to both automobiles and railroad trains.

Designing the airplane. Designing the airplane is far more complicated than designing either the automobile or the railroad train. For one thing, the airplane depends upon air pressure for its forward motion, the propeller boring its way through the air much as a screw bores its way through a board. The automobile, on the other hand, moves forward as a result of the traction of its wheels on street or highway, and the locomotive as a result of the traction of its wheels on rails. As the airplane moves forward, it depends upon air pressure to help it rise and to keep it aloft. At the same time it encounters resistance from the air just as the automobile and locomotive encounter resistance. In other words,

HOW MAN CONTROLS LIQUIDS AND GASES

although the airplane moves forward, rises, and remains aloft because of air pressure, it is also retarded by air pressure.

From the foregoing we can readily see why the design of an airplane is especially important. The airplane must have certain parts, and these parts must have certain shapes and arrangements in order to operate successfully. The structural parts around which air flows in a manner useful in flight are commonly known as airfoils. In general, the parts of an airplane, as shown in

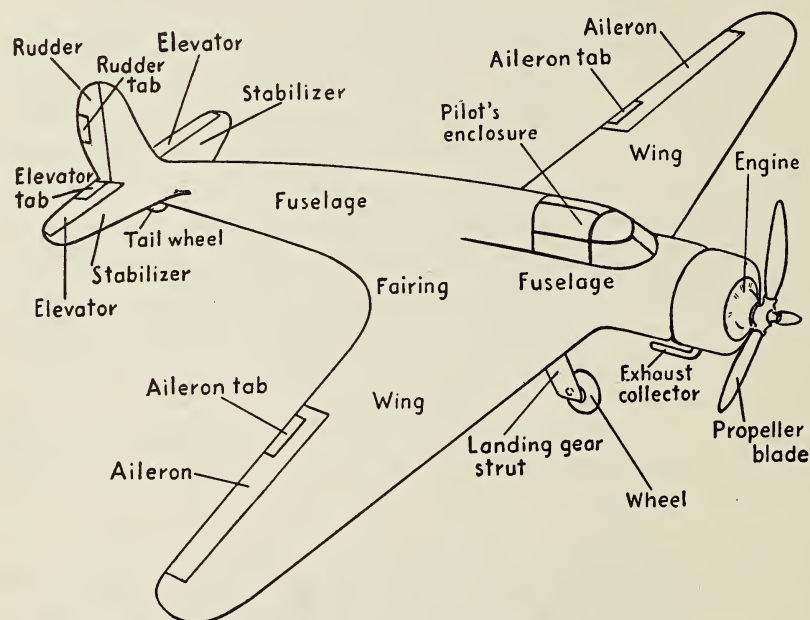


Fig. 34. This figure shows the various parts of an airplane. The principal parts are the wings, the fuselage, the landing gears, the control surfaces, and the engine.

Figure 34, may be classified into five main divisions, as follows: (1) the wings, which furnish most of the lifting surfaces; (2) the fuselage on land planes and the hull on seaplanes, which provide space for the pilot, passengers, baggage, and the like; (3) the landing gears with wheels on land planes and pontoons on seaplanes, which provide a means of taxiing; (4) the control sur-

AIR PRESSURE IN RELATION TO MOTION

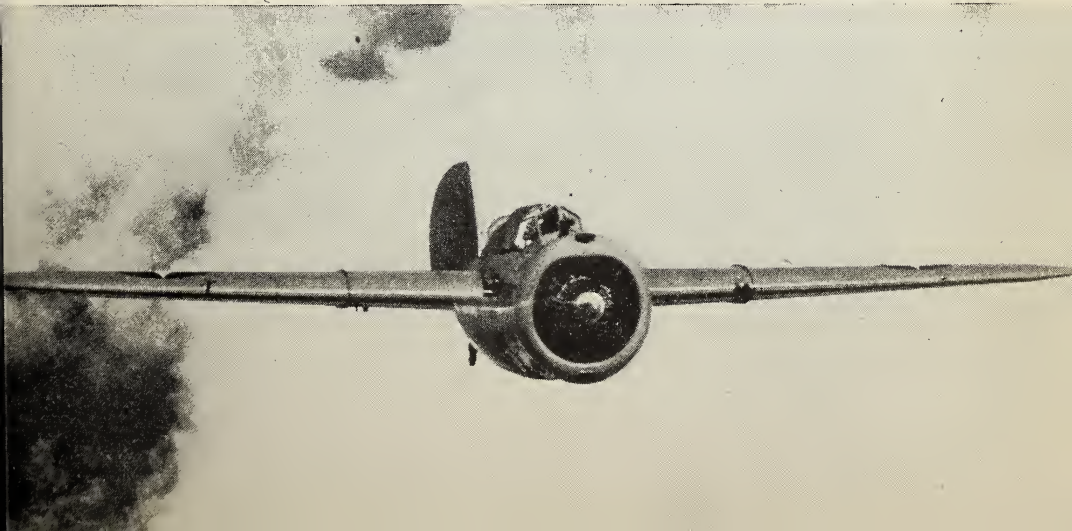
faces, consisting of the movable parts of the wings and tail, which control elevation and direction and provide stabilization; (5) the engine, which rotates the propeller and pulls the airplane forward.

Although all these parts are essential and must be shaped and arranged in certain ways, just as the parts of automobiles must be shaped and arranged in certain ways, yet airplanes differ greatly one from another. Like automobiles, they are built according to different patterns and vary greatly in appearance. In general, they vary to suit the purposes for which they are intended. Thus commercial airplanes meet certain requirements to transport passengers and goods, and army and navy airplanes meet other requirements to render combat duty in war. In order to understand better how airplanes differ, let us consider at greater length the five essential parts named above.

The wings of an airplane. As a general rule, the size of the wings corresponds to the size of airplanes, larger planes having larger wings and smaller planes relatively smaller wings. However, wings vary greatly in size, large airplanes sometimes having surprisingly small wings. The wings also vary greatly in shape, some being long and narrow and others being short and wide. Besides varying in size and shape, wings also vary in number, a monoplane, as its name indicates, having one wing and biplanes having two wings. In the case of the monoplane, which is by far the more common type, the wing may be attached at the bottom of

The efficient performance of this speeding airplane depends to a great extent upon the size and shape of the wings. These wings have been designed both to support the airplane's heavy load and to overcome the tremendous resistance of the air.

Ferdinand Hirsch



HOW MAN CONTROLS LIQUIDS AND GASES

the fuselage, midway of the fuselage, or at the top of the fuselage. In the case of the biplane the wings must be situated either directly over each other or they may be staggered, usually with the upper wing farther forward than the lower wing. Attached to the rear of the wings are certain movable sections, known as ailerons, which are used in banking, or modifying the elevation of flight. Attached to each aileron is a small section known as an aileron tab, which is used in making finer adjustments.

The fuselage or hull. The fuselage of a land airplane may be barrel-shaped, pencil-shaped, or shaped in some intermediate design. In commercial airplanes and certain types of bombers the fuselage is barrel-shaped, whereas in many types of fighter airplanes it is pencil-shaped. In army airplanes the fuselage is modified to make room for gun turrets and gunner stations. If an airplane has one engine, the engine is attached to the nose of the fuselage; if it has more than one engine, the engines are attached to the wings somewhat back of the nose. The hull of a seaplane varies in shape in much the same manner as the fuselage of a land airplane. On the whole, however, there are fewer modifications because seaplanes are less widely used than land airplanes.

The landing gears. The landing gears of a land airplane consist of two wheels with accompanying framework attached to the fuselage or wings near the front, and a third wheel with accompanying framework attached to the fuselage at the rear. All these parts are so planned that they may be drawn up into the structure of the airplane to reduce air resistance after the airplane takes off and let down again to assist the airplane in landing. The landing gears of a seaplane consist of pontoons that resemble the hull of a boat and thus enable the airplane to take off from water and to land upon water. Provision is made in some cases for drawing the pontoons up into the hull or wings during flight and for lowering them again before landing.

The control surfaces. The control surfaces of an airplane include all the movable surfaces, or the parts that may be adjusted to meet the conditions of air pressure. Most of the control surfaces are found in the tail assemblage, which consists of a vertical plane

AIR PRESSURE IN RELATION TO MOTION

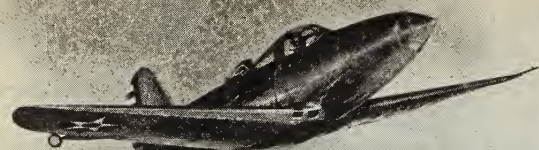
known as the rudder, attached to a fixed vertical plane known as the fin, and two horizontal planes, one on either side of the rudder, known as elevators, attached to a fixed horizontal plane known as the stabilizer. The rudder is used in controlling the direction of flight, and the elevators in controlling the elevation of flight. Attached to the rudder is a small movable section, known as the rudder tab, and attached to the elevators are similar movable sections, known as elevator tabs, which are used in making finer adjustments. In addition to the control surfaces in the tail assemblage, there are also control surfaces on the wings, the ailerons and aileron tabs, which have already been mentioned.

The engine and propeller. The engines in airplanes are usually air-cooled, but some are liquid-cooled, the latter offering less resistance to the air because of their shape. The engines vary in number according to the size and speed of the craft, some airplanes having but one and others having as many as four. Also they vary in location, a single motor always being attached to the nose of the fuselage and multimotors always being attached to the wings. In the latter case the motors may be under the edge of the wings, even with the front edge or above the front edge. In rare instances they are placed back of the rear edge of the wings. The propeller consists of two or three blades, shaped to secure leverage from air pressure and hence pull the airplane forward.

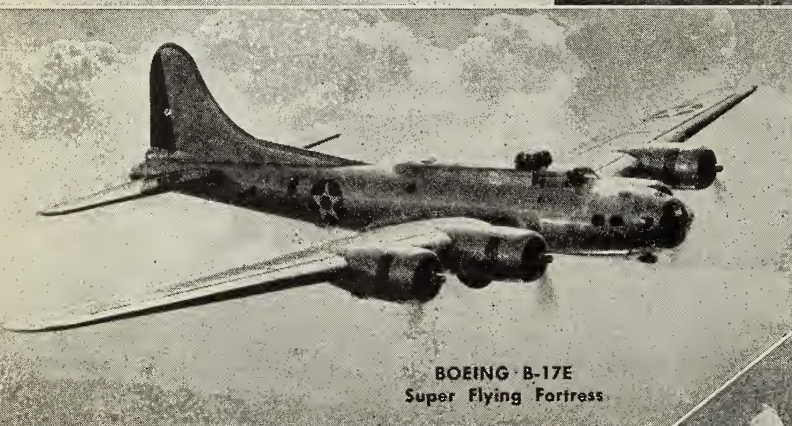
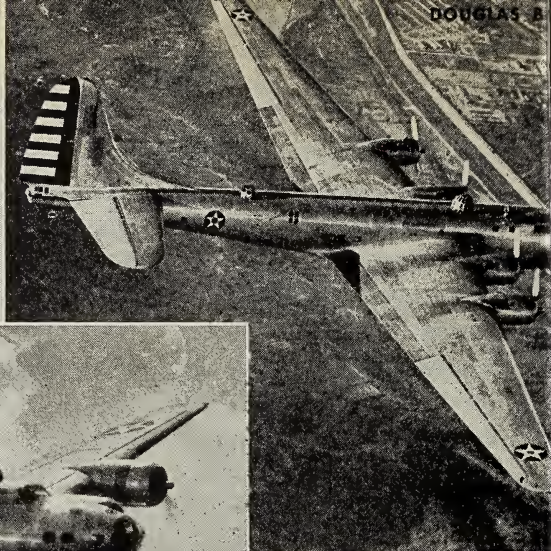
The shape and arrangement of parts enable builders to classify airplanes into many different types. Some of the more important types of army and navy airplanes are shown on the following pages. How many of these types can you identify?

Official U. S. Army and Navy Photographs. On the two succeeding pages you will find official photographs of airplanes used by the armed forces of our country. The operation and construction of these airplanes depend upon the application of certain principles of physics such as you are studying in this book. Among the more important principles that must be considered are those governing air pressure, forces, heat, magnetism, and electricity. Without a thorough knowledge of these principles, pilots, radio men, and bombardiers could not read complicated instruments, calculate distances accurately, time their activities to fractions of a second, or do other things to operate the fighters successfully. Without a knowledge of the principles of physics, likewise, engineers could not draw blueprints for the building of such excellent fighters, nor could they even design the large factories in which the fighters are made.

DOUGLAS B



BELL P-39
Airacobra

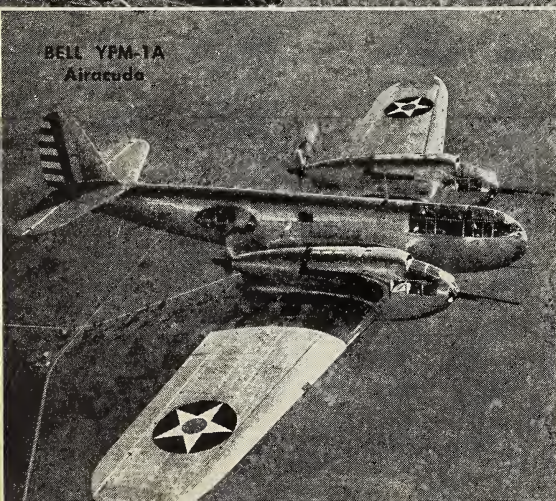
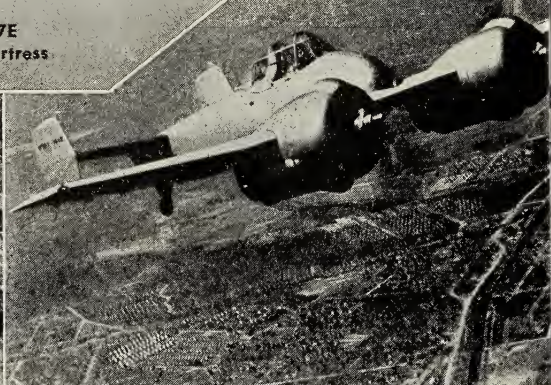


BOEING B-17E
Super Flying Fortress

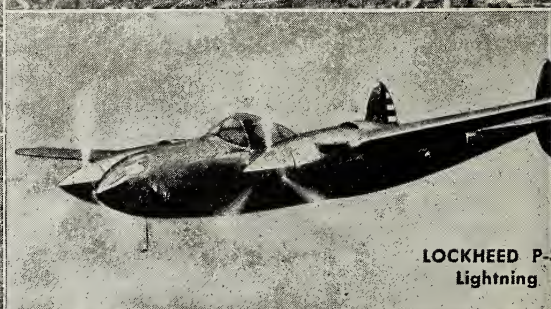
GRUMMAN XF5F-1
Skyrocket



VOUGHT-SIKORSKY SB2U-1
Vindicator



BELL YPM-1A
Airacuda



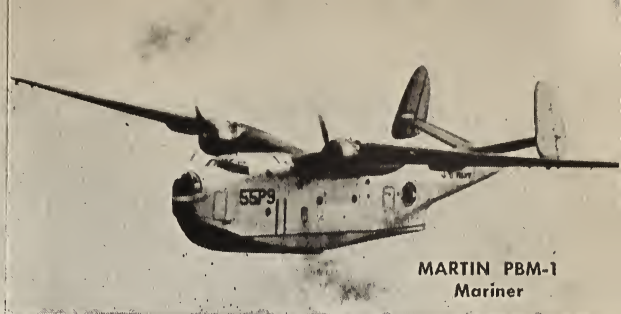
LOCKHEED P-38
Lightning



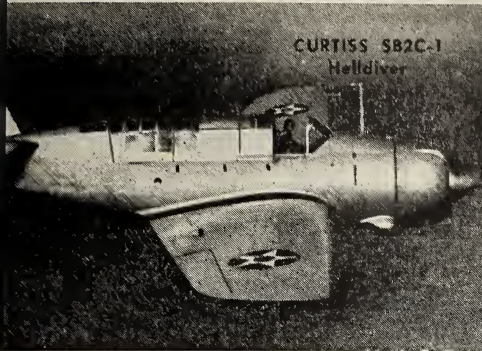
VOUGHT-SIKORSKY F4U-1
Corsair



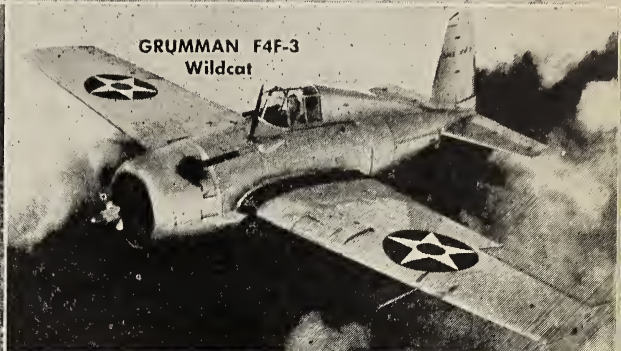
CURTISS SO3C-1
Seagull



MARTIN PBM-1
Mariner

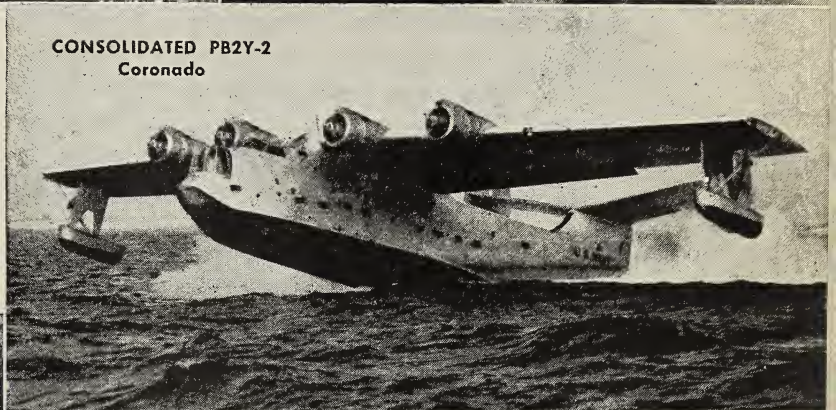


CURTISS SB2C-1
Helldiver

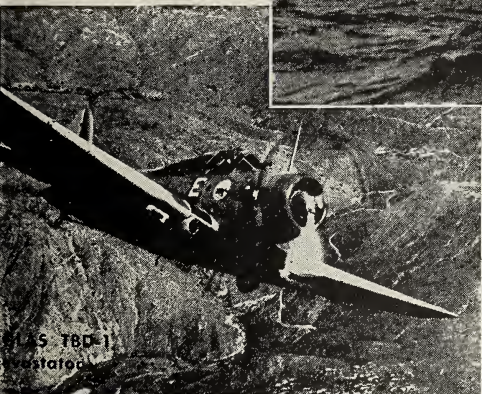


GRUMMAN F4F-3
Wildcat

UNITED STATES ARMY and NAVY AIRCRAFT



CONSOLIDATED PB2Y-2
Coronado



GRUMMAN TBD-1
Devastator



BREWSTER XF2A-2
Buffalo



VOUGHT-SIKORSKY SO2U-1
Kingfisher



CONSOLIDATED P4M-1
Catalina

HOW MAN CONTROLS LIQUIDS AND GASES

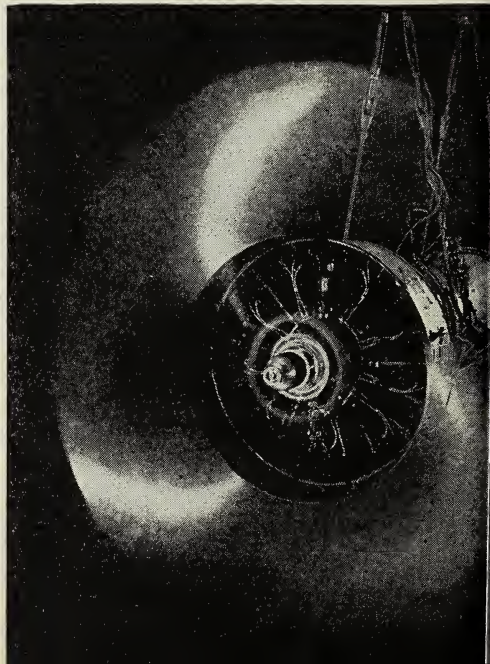
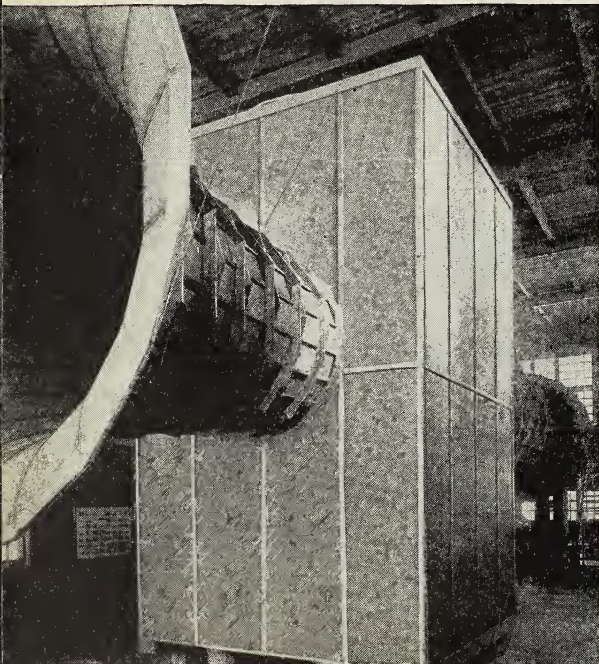
Designing the glider. The glider is an especially interesting type of aircraft because it flies without any power of its own. In design it resembles the airplane and, with the exception of the engine and propeller, has all the essential parts of an airplane. When it takes off, it must be pulled or catapulted into the air, but once started it depends entirely upon air pressure as a means of remaining aloft and continuing its flight. It may stay in the air for many hours at a time and reach surprisingly high altitudes. The glider is used chiefly in training pilots and in the transportation of troops in time of war. It is also used widely in sports, pilots often entering into contests to see how long, how far, or how high they may fly after a single take-off.

AERODYNAMICS

Aerodynamics and the wind tunnel. Now let us consider how an airplane depends upon the atmosphere for buoyancy, or how it rises and supports itself in the air. The branch of physics that explains the buoyancy of the atmosphere is commonly known as aerodynamics. Technically, aerodynamics is a study of the forces acting upon an object as a result of the relative motion

The picture at the left shows the exterior of a wind tunnel such as is used in airplane factories for testing the parts of airplanes exposed to the wind. The picture at the right shows an airplane engine facing a strong current of air inside a wind tunnel.

Ewing Galloway



AIR PRESSURE IN RELATION TO MOTION

of the object and air. In other words, it is concerned with the forces acting upon an object when the object moves through the air, when the air moves past the object, or when both these movements take place. In order to observe the effects of the relative motion of an object and air, scientists commonly use a large tube similar to that shown in Figure 35 and known as a wind tunnel.

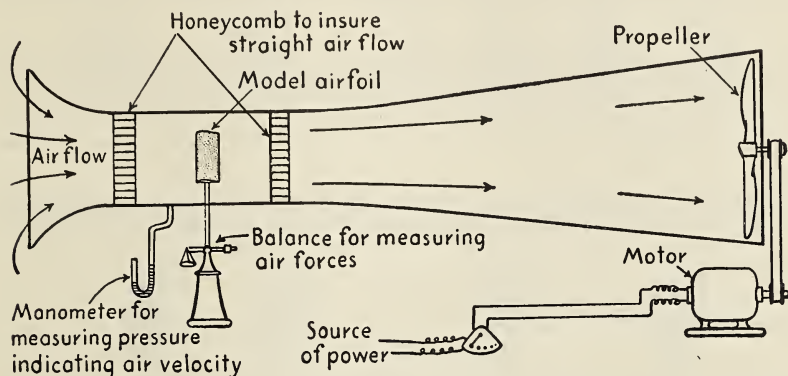


Fig. 35. This drawing shows the essential parts of a wind tunnel, such as the long tube, the propeller for producing the current, and the apparatus for measuring the current.

Objects are placed in the tunnel, and air is forced through at varying rates of speed. The wind tunnel is especially helpful in the field of aeronautics since it enables persons to study at ground level the forces that affect an airplane in flight. Such a tunnel in some cases is extremely large—large enough to accommodate a complete airplane so that the forces may be studied in relation to all parts at once.

An old principle comes to life. The principle that explains how air pressure provides buoyancy for an airplane was discovered about two hundred years ago by a Swiss mathematician named Bernoulli. In performing his experiments, Bernoulli worked only with liquids, but other scientists found later that the principle applies equally well to gases. These scientists little realized how important the principle would become to the world, but today it

HOW MAN CONTROLS LIQUIDS AND GASES

is exceedingly important, for it explains how airplanes secure the necessary lifting pressure to stay in the air.

Technically, Bernoulli's principle may be stated as follows: *The pressure of a fluid, either liquid or gas, decreases as the velocity increases and increases as the velocity decreases.* Thus if we force a fluid through a pipe of uniform diameter, as shown in Figure 36, and test the pressure of the fluid on the wall of the pipe by

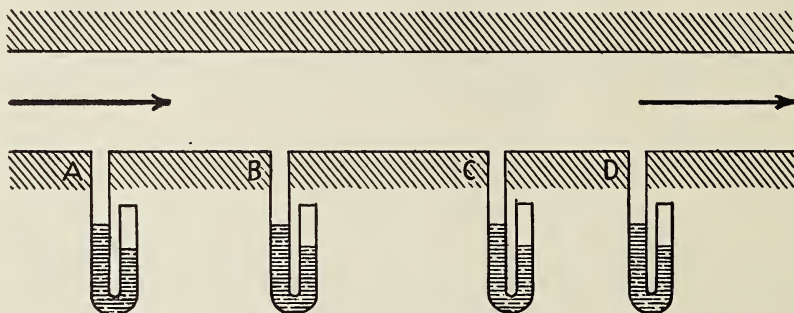


Fig. 36. The uniform height of the mercury in the shorter arms of the manometer tubes attached to the pipe shows that the pressure is uniform at all points in the pipe.

attaching at irregular points, such as A, B, C, and D, U-shaped tubes containing mercury, known as manometer tubes, we find that the mercury in the shorter arms of the tubes stands at the same level. The uniform height of the mercury in the shorter arms shows that the pressure at all the points is the same. On the other hand, if we force a fluid through a pipe known as a Venturi tube, shown in Figure 37, which contains a constricted section with diameters gradually decreasing to a certain size and then gradually increasing to the original size, and test the pressure by attaching manometer tubes at irregular points, such as A, B, C, D, E, and F, we find that the mercury in the shorter arms of the tubes attached to the smaller section of the pipe is lower than the mercury in the shorter arms of the tubes attached to the larger sections of the pipe. The differences in the height of the mercury in the shorter arms show that the pressure decreases from points A to C, C being the point of greatest con-

AIR PRESSURE IN RELATION TO MOTION

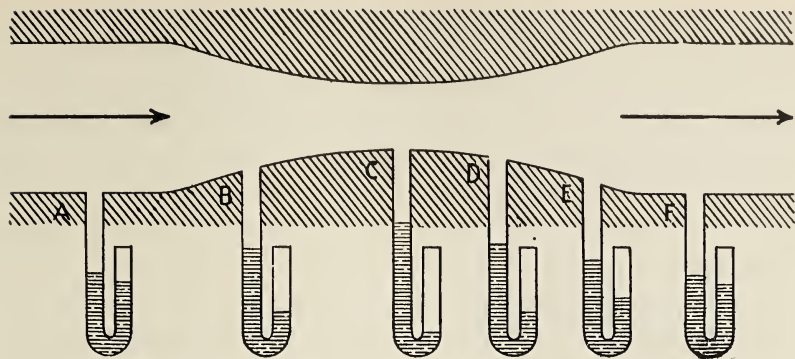


Fig. 37. The different heights of the mercury in the shorter arms of the manometer tubes attached to the pipe show that the pressure varies at different points in the pipe.

striction, and increases again from points *C* to *F*. If we were to test the velocity of the fluid as it moves through the pipe, we should find that the velocity increases as the pipe becomes smaller and decreases again as it becomes larger. The changes in velocity account for the variations in pressure.

Interesting applications of Bernoulli's principle. As already stated, Bernoulli devised his principle by experimenting with fluids passing through pipes, but other scientists have proved that the principle applies equally well to gases, such as air, moving outside of pipes. There are several simple experiments that we may perform to show that this is true. If we put a thumbtack in a cardboard, for instance, place the cardboard over the lower end of a spool held vertically, as shown in Figure 38, and blow downward rather gently through the spool, we find that the cardboard clings to the spool without support. This behavior may be explained by the fact that the still air on the lower side of the cardboard, or the side away from the spool, exerts greater pressure than the moving air on the upper side.

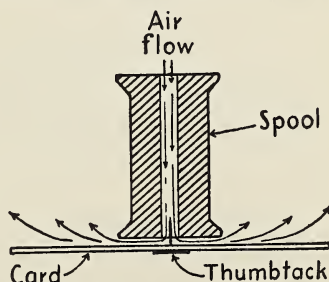


Fig. 38. The cardboard clings to the spool because of the movement of air.

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As a second experiment we may hang in the open a small, light ball such as a ping-pong ball as shown at the left in Figure 39, and blow a stream of air through a straw past the ball. To our surprise, we find that the ball moves toward the end of the straw rather than away from it. This behavior may be explained by the fact that the still air on the side of the ball away from the straw exerts greater pressure than the moving air on the side of the ball nearer the straw.

As a third experiment we may place a light ball upon the end of a vertical straw, as shown at the right in Figure 39, and blow a stream of air through the straw. In this case the ball rises to a point in the air above the straw, where it dances about as long as we continue to blow. This behavior, or the riding of the ball

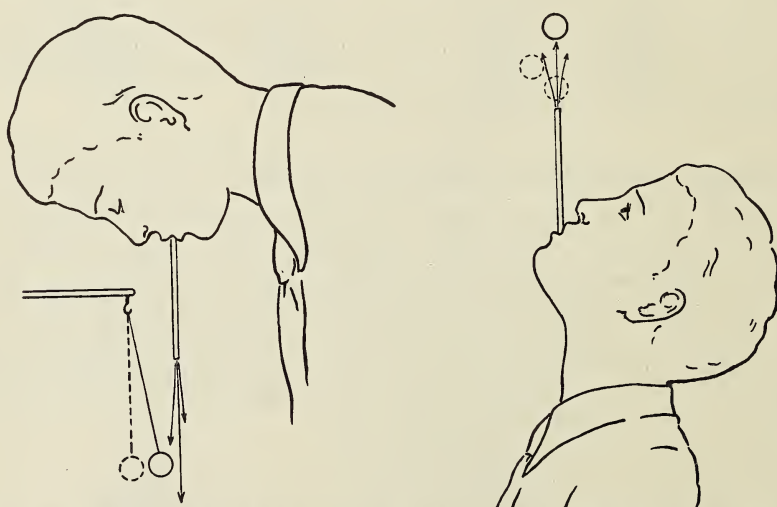


Fig. 39. The drawing at the left shows how a small suspended ball moves toward a jet of air, and the drawing at the right how a loose ball rides, or dances, in a jet of air.

in the jet of air, may be explained by the fact that the still air outside the jet exerts a greater pressure against the ball than the moving air in the jet and hence forces the ball back into the jet whenever it tends to escape into the still air. .

AIR PRESSURE IN RELATION TO MOTION

Bernoulli's principle applied to the wing of an airplane. Let us now apply Bernoulli's principle to the movement of air between two surfaces, as shown by the upper drawing in Figure 40. The movement of the air, or the paths of the air currents, are illustrated by the lines in the drawing known as streamlines. These streamlines, as we can see, tend to follow the curved surfaces above and below. The air entering at *A* passes through the smaller space at *B* and occupies more space again at *C*. Thus the velocity at *B* is greater than the velocity at *A* or *C*, and the air pressure at *B* is less than the pressure at *A* or *C*.

Now let us follow the streamlines when the two surfaces are placed farther apart, as shown in the middle drawing in Figure 40. Here again the lines tend to follow the curved surface above and below, but the farther the lines are from the surface the less they are curved, and those near the center are practically straight. As in the first situation, however, the velocity of the air at *B* is greater than the velocity at *A* or *C*, and hence the air pressure at *B* is less than the pressure at *A* or *C*.

Finally, let us follow the streamlines when the upper surface is completely removed, as shown in the lower drawing in Figure 40. Here the streamlines next to the curved surface below tend

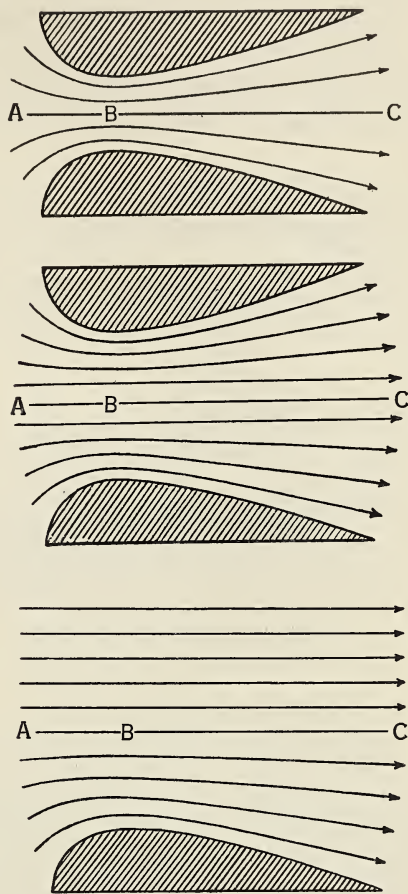


Fig. 40. These drawings show how streamlines, or the paths of air currents, are affected by surfaces above and below.

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to follow the curved surface, but those farther away are less curved and those some distance away are perfectly straight. As when both surfaces are present, the velocity of the air at *B* is greater than the velocity at *A* or *C*, and therefore the air pressure at *B* is less than the pressure at *A* or *C*.

On the basis of the foregoing illustrations we can readily see how Bernoulli's principle helps to explain the lifting force of the air. When the air passes an airplane wing as shown in the upper

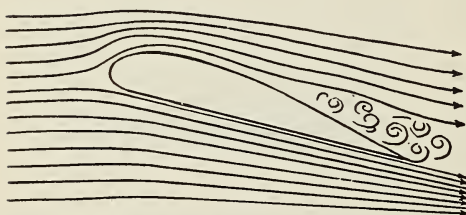
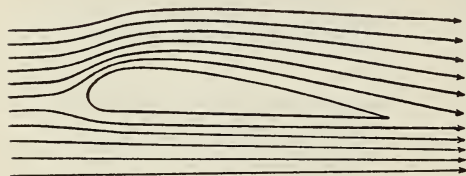


Fig. 41. These drawings show how streamlines are affected by the surfaces of an airplane wing.

drawing in Figure 41, the streamlines curve according to the curved upper surface of the wing, whereas those below the wing are fairly straight because the lower surface of the wing is fairly straight. Thus the velocity of the air above the wing is greater than the velocity below the wing, and the pressure above the wing is less than the pressure below the wing. This difference in pressure accounts for the

buoyancy of air and is sufficient to hold the airplane aloft. If the wing is tilted slightly, as shown in the lower drawing in Figure 41, the lifting force is still greater. Since the wing splits the air at an angle, it acts somewhat as does a flat stone that skims along the surface of water when we throw it with its front edge slightly tilted upward. Back of the wing in this instance, however, is a small region of relatively motionless air, as shown in the drawing, which tends to retard somewhat the lift of the wing. This discussion and these illustrations give us an indication of how closely the science of physics is related to airplane design, and especially to the designing of airplane wings. Certainly, an aeronautical engineer must know Bernoulli's principle thoroughly.

AIR PRESSURE IN RELATION TO MOTION

AIRPLANE INSTRUMENTS DEPENDING UPON AIR PRESSURE

The altimeter. One important airplane instrument that depends upon air pressure for operation is the altimeter, the interior of which is shown in Figure 42. This instrument, as its name indicates, is used in determining the altitude of flight, much as an aneroid barometer is used in determining elevation. In construction it closely resembles an aneroid barometer, except that it is calibrated to show feet above sea level rather than to show inches of pressure on a mercurial barometer. In most instances the calibration is such that the point makes one complete revolution in a climb from sea level to 10,000 feet. After reaching 10,000 feet, it starts a second revolution, which it completes at 20,000 feet, after which it begins a third revolution. Thus when a pilot is 7000 feet high, the reading is 7000,

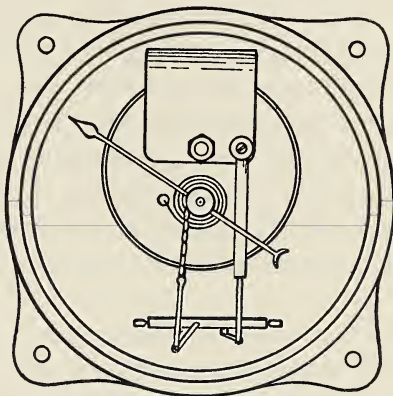
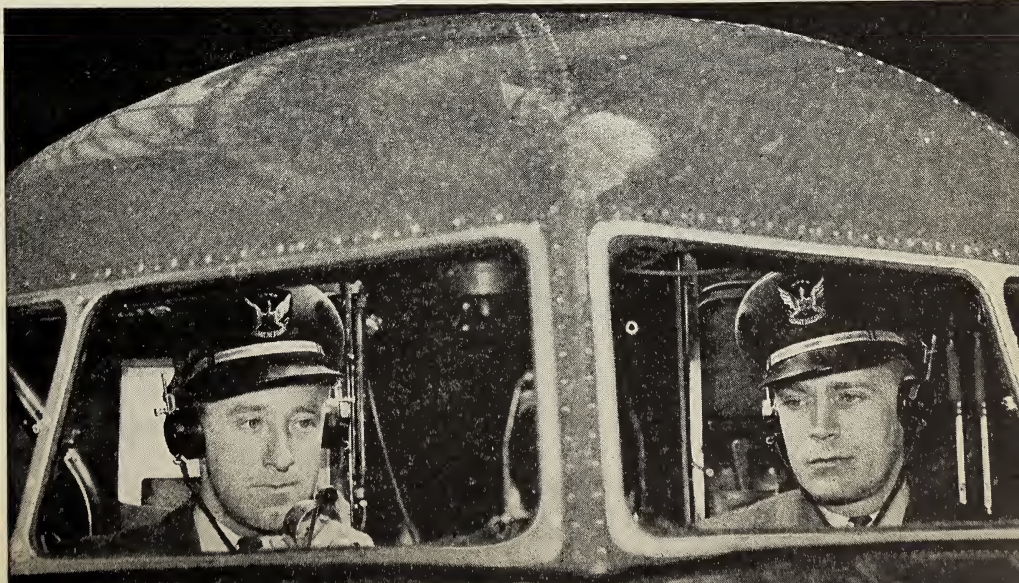


Fig. 42. A diagram showing the working parts of the altimeter of an airplane.

The pilot and co-pilot of an airplane must use many instruments in order to direct an airplane successfully in flight. Most of these instruments, including the altimeter which is illustrated above, are conveniently located on an instrument board in front.

United Air Lines



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and when he is 17,000 feet high, the reading is again 7000, but he realizes that the second reading is on the second revolution and hence interprets the reading correctly. In some instances the altimeter is provided with two pointers, one of which moves around once in an elevation of 1000 feet and the other once in an elevation of 10,000 feet. Such an altimeter enables the pilot to read the elevation with greater accuracy, just as a watch with a second hand enables a person to measure time with greater accuracy than a watch with a minute hand alone.

Although the altimeter regularly indicates elevation above sea level, it may be set to show elevation above the point of departure. In other words, the pilot may adjust the instrument so that the hand on the dial points to zero at the airport, in which case he determines the height above the airport rather than the height above sea level during the flight. Sometimes, also, the pilot may make certain adjustments during the flight, as when the barometric pressure is radioed to him by the Weather Bureau.

Rate-of-climb indicator. Another important airplane instrument that depends upon air pressure for operation is the rate-of-climb indicator, shown in Figure 43. This instrument consists of an airtight case that is divided into two compartments by a

mounted diaphragm somewhat like the diaphragm of an aneroid barometer. Connected with the diaphragm is a system of levers that operates the pointer on the dial. The compartment on one side of the diaphragm is open to outside air pressure and is connected with the other compartment by a calibrated diffuser through which air leaks, or diffuses, very slowly. When the airplane is in level flight, the air pressure on both sides of the

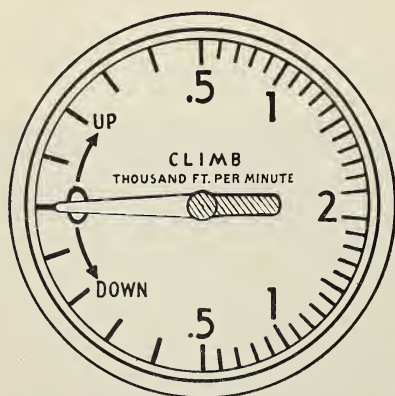
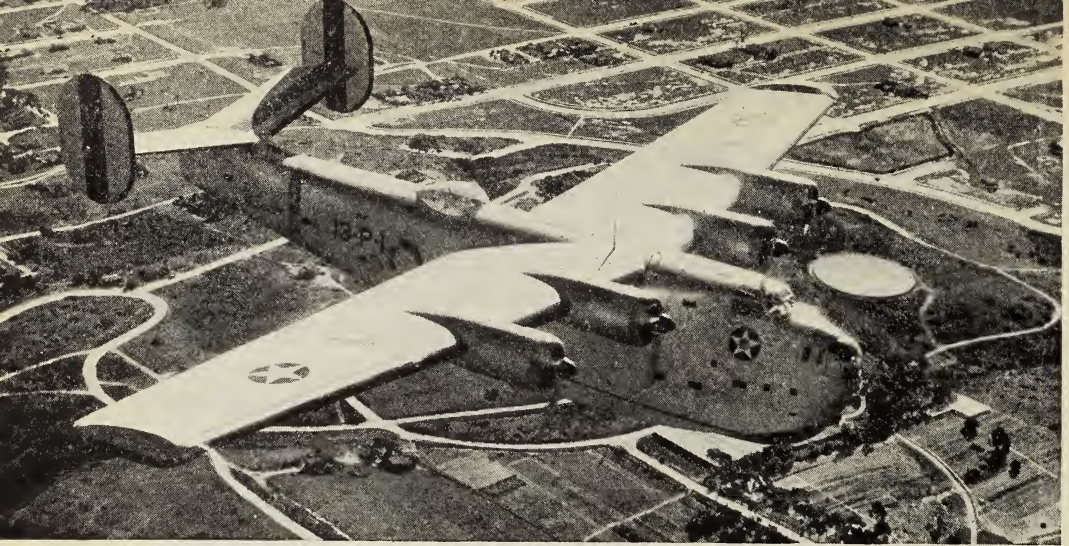


Fig. 43. A diagram showing the dial of the rate-of-climb indicator of an airplane.

diaphragm is the same, and the pointer reads zero. When the airplane climbs or descends, the air pressure changes more rapidly in the one compartment than in the other because of the calibrated diffuser, and the diaphragm expands or collapses, moving the pointer on the dial. That is, when the airplane ascends the pointer on the dial indicates ascent, and when the airplane descends the pointer indicates descent.

The instrument is extremely sensitive, recording the slightest ascent or descent when the plane is in flight. It may be adjusted, if necessary, to take care of varying conditions that arise as a result of storms. The adjustments must be made exactly, however, because the time lag required for equalizing the pressure between one side of the diaphragm and the other must be short enough to allow the pointer promptly to indicate changes in altitude, but not short enough to cause the pointer to fluctuate violently in turbulent air. Most rate-of-climb indicators register a rate of ascent or descent of 2000 feet per minute with a half-revolution of the pointer on the dial. Some instruments register as much as 4000 feet per minute with a half-revolution of the pointer. The instruments used in balloons, gliders, and dirigibles usually are more sensitive than those used in airplanes and have a somewhat shorter range.

The speed indicator. Still another important airplane instrument depending upon air pressure for operation is the speed indicator. This instrument consists of a diaphragm set in a cylinder that is connected by a long copper pipe with an open tube that points forward outside the airplane. A system of levers connected with the diaphragm operates a pointer on a dial that is calibrated to show miles per hour. As the airplane moves forward, air enters the open tube on the outside and passes along to the cylinder, where it exerts pressure upon the diaphragm. This pressure, which represents pressure in addition to ordinary atmospheric pressure, is known as dynamic pressure. The dynamic pressure acting upon the diaphragm causes the levers to turn the pointer on the dial and thus to indicate the speed of flight.



Ferdinand Hirsh

The picture shows clearly the airfoils of an airplane. Some of them are movable, and can be manipulated by the pilot so that he can control the effects of the air flow upon the airfoils and thus control the performance of the airplane.

ANSWER THESE QUESTIONS

1. Why does air offer resistance to a moving object?
2. How do manufacturers of automobiles and fast-moving railroad trains seek to lessen the resistance of air?
3. Why is the design of an airplane more important than the design of an automobile or a railroad train?
4. What are the essential parts of an airplane? How may the parts of an airplane be classified? How may the parts differ in different types of airplanes?
5. How does a glider differ from an airplane? How are gliders commonly used?
6. What is meant by aerodynamics?
7. What is a wind tunnel? Why is the wind tunnel especially important in a study of aviation?
8. What is Bernoulli's principle? How may we demonstrate the principle through the use of two kinds of pipes or tubes?
9. How does Bernoulli's principle apply to the pressure of fluids moving outside of pipes?
10. What simple experiments may we perform to show that the principle applies to air outside pipes or tubes?
11. How does Bernoulli's principle apply when one of two neighboring surfaces is removed from the other? What paths do the air streams follow in such a case?

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12. What happens when the air passes above and below the wing of an airplane? Why does the air beneath the wing provide greater pressure than the air above the wing?

13. Why does a wing have a greater lifting force when it is tilted slightly upward in front?

14. How does an altimeter work? What other instrument does it resemble? How is it calibrated?

15. What is the speed indicator of an airplane? What are its principal parts? How is it calibrated?

AREA SIX

How Is a Confined Gas Affected by Pressure?

Frequently we have experiences which show that air under pressure is resilient, or springy. For example, if we hold a finger firmly over the end of the hose of a bicycle pump, we find that we have difficulty in pushing down the handle. If we keep the air from escaping through the hose and then release the handle, it springs upward. All this shows that some sort of relation exists between the pressure exerted by the handle and the space occupied by the compressed air. Let us now see what the relation is between the pressure and the space.

An explanation of Boyle's law. The first person to determine the exact relation that exists between the pressure and volume of a gas was an English physicist by the name of Robert Boyle. This famous scientist applied varying pressures to a column of trapped air and studied the effects of the pressures upon the volume of the air. Keeping the gas at constant temperature to avoid discrepancies, he found that when he doubled the pressure on the gas, the volume became one-half as great; when he trebled the pressure, the volume became one-third as great; and so on. In other words, he found that the volume was continuously inversely proportional to the pressure. The term *inversely proportional* means that one quantity increases in the same ratio as another quantity decreases, or vice versa.

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For purposes of study Boyle's law is commonly stated thus: *If the temperature remains constant, the volume of a gas is inversely proportional to the pressure.* If we let P_1 represent the pressure exerted upon the gas in a given container, V_1 the corresponding volume, P_2 a greater pressure, and V_2 the corresponding volume, we may express the law in the form of an equation as follows:

$$\frac{V_1}{V_2} = \frac{P_2}{P_1}.$$

Clearing of fractions, $V_1P_1 = V_2P_2.$

Example. A tank whose volume is 20 cubic inches is filled with air that exerts a pressure of 30 pounds per square inch. What pressure will the air exert if the volume of the tank is increased to 50 cubic inches?

Solution. To solve this problem, we substitute 20 for V_1 , 30 for P_1 , and 50 for V_2 in the foregoing equation as follows:

$$20 \times 30 = 50 \times P_2.$$

Transposing and multiplying,

$$50 P_2 = 600.$$

Therefore

$$P_2 = 12 \text{ pounds per square inch.}$$

From the foregoing equation we readily see that the first volume of the tank multiplied by the first pressure exactly equals the second volume multiplied by the second pressure. In other words, we see that the volume multiplied by the pressure remains the same and hence may be said to be constant. For this reason Boyle's law is frequently expressed as follows: *If the temperature is unchanged, the pressure of a confined gas multiplied by its volume is constant.*

If we let V represent the volume of any container, P the pressure, and K the content, we may express the law as follows:

$$V_1P_1 = K.$$

Substituting in this equation the volume and pressure given for the smaller tank in the foregoing example, we have:

$$20 \times 30 = K.$$

Transposing and multiplying,

$$K = 600.$$

Robert Boyle
(1627-1691)

Robert Boyle was a noted English philosopher and scientist. Even though he lived about three hundred years ago, he was greatly interested in experimental science and performed many experiments with liquids and gases. His greatest contribution to physics is the law that explains the relation between the pressure of a gas and its volume. He also made important findings in the field of chemistry.



Substituting in the equation the volume and pressure given for the larger tank in the foregoing example, we have:

$$50 \times 12 = K.$$

Transposing and multiplying,

$$K = 600.$$

Boyle's law and the density of gases. Boyle's law, as we may conclude from the foregoing, is directly concerned with density. A gas, like any other matter, according to the commonly accepted molecular theory, is composed of molecules and these molecules are in constant motion. As they move about, they collide with one another. If they are confined in a container, they collide with the walls of the container. Whenever we put a given quantity of gas into a smaller container, we crowd the molecules more closely together and they apparently collide more often than before. In other words, if we put a given quantity of air into a container half as large, we crowd the same number of molecules into half the space. If the temperature remains constant, we may assume that they collide twice as often because the pressure is twice as great. On the contrary, if we put a given quantity of air into a container twice as large, we release the same number of molecules into a space twice as large. If the temperature remains constant, we may assume that they collide half as often as before because the pressure is one-half as great. From these

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observations we may readily conclude that the density of a gas is directly proportional to its pressure. In other words, we may extend the meaning of Boyle's law by including a statement on density as follows: *If the temperature of a confined gas remains constant, the pressure is inversely proportional to the volume of the gas and directly proportional to the density.*

Illustrating Boyle's law with the Cartesian diver. One way in which to illustrate Boyle's law is through the use of a device known as the Cartesian diver. This device consists of a glass container



Fig. 44. A Cartesian diver.

somewhat like a bottle or test tube, partly filled with water and submerged in an inverted position in a larger vessel of water as shown in Figure 44. The air and the water in the inverted container are adjusted to such proportions that the container floats in a submerged position. Over the top of the larger vessel is a rubber diaphragm, or covering, that may be moved upward or downward, thus changing the pressure on the surface of the water and causing the inverted container to rise and sink. How may we explain this behavior in terms of Boyle's law?

Besides illustrating Boyle's law, the Cartesian diver illustrates Archimedes' principle. The test tube, like other objects in water, is buoyed up by a force equal to the weight of the water displaced. Without the variations in pressure caused by the vibrations of the membrane, the test tube would float at a single level. The Cartesian diver also illustrates Pascal's law, since the pressure caused by the vibrations of the membrane is transmitted equally and undiminished in all directions.

Plotting a curve on the basis of Boyle's law. To understand better the meaning of Boyle's law, we may wish to gather certain data on the basis of the law and use these data in plotting a curve. First, we pour mercury into a capillary tube and trap a column of air; second, we fasten the tube to a meter stick with the end containing the column of trapped air exactly even with the bot-



The girl at the left is testing Boyle's law by measuring a column of air in a tube and the column of mercury above that traps the air in the tube. The boy at the right is performing the same experiment by using a small tank of compressed air.

tom of the stick; and third, we mount the meter stick upon an upright so that it can be turned to any desired angle. When we have set up the apparatus in this manner, we place the meter stick in a vertical position with the column of trapped air at the bottom of the attached tube and measure the length of the column of trapped air in centimeters. Then, in order to calculate the pressure exerted upon the trapped air, we measure the height of the column of mercury in centimeters and add the barometric reading in centimeters for the regular atmospheric pressure above the column of mercury.

When we have finished these readings, we rotate the meter stick clockwise through an angle of 20° and measure the height of the column of air along the meter stick as before. We vary the method of calculating the pressure upon the trapped air, how-

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ever, because the column of mercury is now partly supported by the slanting tube. Hence we determine the pressure of the column of mercury by subtracting the distance, measured in

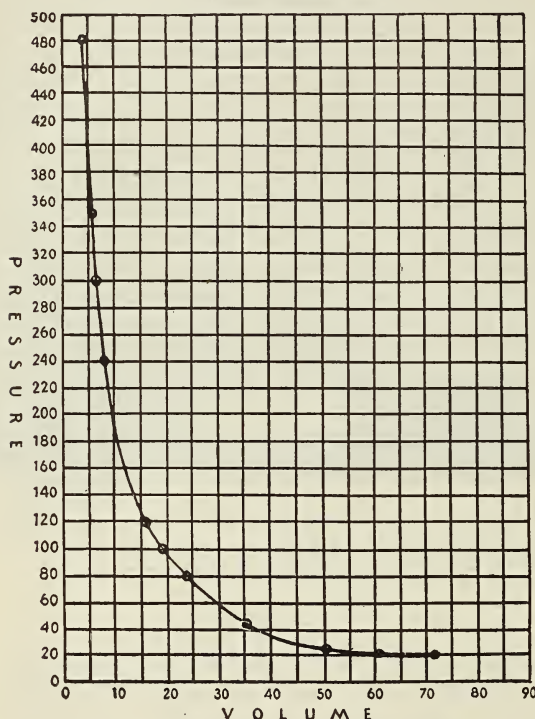


Fig. 45. The curve above shows the relation of the volume of trapped air to its pressure. What readings were made before the curve could be drawn?

centimeters, between the laboratory table and the bottom of the column from the distance, measured in centimeters, between the table and the top of the column. To this difference, in order to find the total pressure, we add the barometric reading in centimeters for the regular atmospheric pressure above the column of mercury.

When we have finished these readings, we rotate the meter stick clockwise to various other positions and take readings. Then we check the measurements which we have obtained and proceed

to plot a curve similar to that shown in Figure 45. This curve, when completed for the various readings, should show an inverse relationship between the volume of the trapped air and the pressure, the former decreasing as the latter increases.

The vacuum pump. One of the most common devices depending upon the principles expressed in Boyle's law is the ordinary vacuum pump. When we push down upon the handle of such a pump, we raise the piston and create a vacuum in chamber *R*

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as shown in Figure 46. At the same time valve *B* opens and part of the air in chamber *S* passes into chamber *R*. When we raise the handle, we lower the piston, close valve *B*, and open valve *A*, thus forcing the air from chamber *R* below the piston to the chamber above the piston, from which it passes to the outside. As we continue the operation, we cause more and more air to pass from chamber *S*

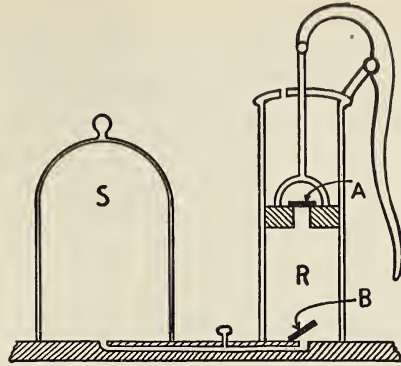


Fig. 46. The above drawing shows the essential parts of an ordinary vacuum pump.

to chamber *R* and from there to the outside, but we can never hope to create a complete vacuum because the remaining air, even when rare, continues to expand and fill all the space. Most vacuum pumps are motor-driven, the motors operating in oil to prevent leaks. An exceptionally good vacuum pump reduces the pressure of air to about one-thousandth millimeter of mercury, but even this pressure is too high for light bulbs, radio tubes, and X-ray tubes. To secure a still greater vacuum, other methods of exhausting air must be used.

The vacuum cleaner. A common device that operates upon the same principle as the vacuum pump is the vacuum cleaner. The nozzle of the cleaner corresponds to the bell jar of the vacuum pump, the motor-driven fan to the piston, and the dust bag to the outlet, but the cleaner contains no valves. When the fan runs at a high rate of speed, it tends to create a vacuum in the nozzle and air rushes into the nozzle from the surface of the carpet or other surface being cleaned, carrying with it loose material and dust. Both the air and the dust pass into the dust bag, in which the dust remains but from which the air escapes because the bag is made of semiporous materials. The foregoing comparison with a vacuum pump is not complete in every respect, yet it is sufficient to show the principle involved. The vacuum cleaner

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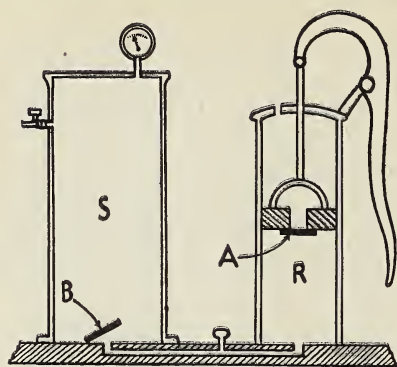


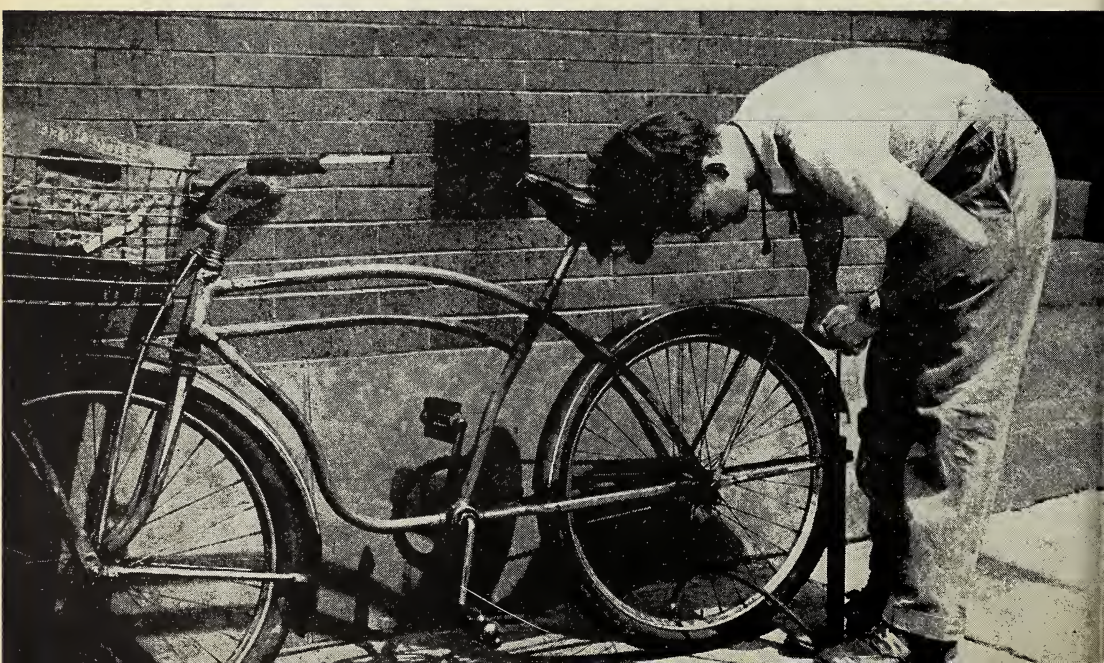
Fig. 47. The above drawing shows the essential parts of an ordinary compression pump.

is widely used in homes where electricity is available. Besides cleaning rugs and carpets, it also cleans furniture and curtains and hence saves the housewife many hours of drudgery.

The compression pump. Another common device depending upon the principle expressed in Boyle's law is the compression pump. This pump, as its name indicates, serves a purpose directly opposite from that of the vacuum pump. When we push down upon the handle of a compression pump as shown in Figure 47, we raise the piston and open valve A, causing air from above the piston to flow into chamber R below the piston. When we raise the handle, we lower the piston and close valve A, thus forcing air from chamber R through valve B into chamber S, which is to be filled. This operation continues until the air in the tank acquires the desired pressure. The compression pump is

This boy with his bicycle is inflating a tire by means of a compression pump. A hand pump, such as this, operates according to the same principles as the pump illustrated above. The valve that retains the compressed air is located in the stem of the tire.

Ferdinand Hirsch



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widely used at filling stations for inflating automobile tires. The condensed air is stored in tanks from which it is released by the attendant as needed. The pump is usually operated by an electric motor, if electricity is available, because pumping by hand is a tedious and difficult task.

The Westinghouse air brakes. Among the most important devices depending upon air pressure are air brakes, which help to stop and regulate the speed of railroad trains and certain large motor vehicles such as busses and trucks. When railroads were new, trains were controlled by mechanical brakes, each car having brakes of its own adjusted by the turning of a wheel at the top. When an engineer wished to stop a train, he gave a signal with the whistle, and the trainmen ran from car to car turning the wheels to clamp down the brakes. Such a system was very unsatisfactory, and many wrecks occurred because trains could not be brought under control quickly.

In 1868 an American inventor by the name of George Westinghouse laid the foundation for overcoming many of the difficulties in braking trains by inventing a system of air brakes controlled by the engineer in his cab. This system consists of a main compressed-air chamber on the engine and pipes that lead to auxiliary air tanks on the various cars, with hose connections between the cars. The air from the auxiliary air tanks on each car passes through pipes to brake cylinders, where it moves the pistons and causes the brake shoes to rub against the rims of the wheels. When the pressure is released, a spring in each brake unit pulls the brake shoes away from the rim.

The operation of the Westinghouse brakes depends upon the use of a three-way valve that permits connections: first, between the main line and each auxiliary chamber; second, between each auxiliary chamber and each brake cylinder; and third, between each brake cylinder and the atmosphere. To set the brakes, the engineer adjusts the valve in such a way as to allow air to rush from each auxiliary chamber to each brake cylinder. To release the brakes, he adjusts the valve in such a way as to

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release the air from the brake cylinders into the atmosphere. The system is arranged so that the brakes may be applied only when the air is shut off from the main line. This is especially important from the standpoint of safety, for the brakes operate when a train breaks in two, thus preventing many wrecks. The brakes operate with exceedingly great speed, if necessary within a fraction of a second.

Measuring the pressure of a gas. If the pressure of a gas is low, it is commonly measured in the laboratory by means of an open manometer tube as described in Area One. When no pressure except atmospheric pressure is exerted upon the mercury in the tube, the mercury stands at the same level in both arms. When the shorter arm of the tube is attached to a vessel containing gas under pressure, however, this pressure causes the mercury to fall in the shorter arm and to rise in the longer arm. The difference in the level of mercury in the two arms represents the pressure of the gas over and above the atmospheric pressure. In order to calculate the pressure in grams per square centimeter or pounds per square inch on the basis of this difference, we merely substitute known quantities in the equation $p = hd$.

Example. Suppose the open arm of a manometer tube is attached to a vessel containing gas under pressure and the mercury in the larger arm is 5 centimeters higher than the mercury in the shorter arm. What pressure does the gas exert?

Solution. To solve this problem, we substitute 5 centimeters for h , and 13.6 grams (the density of mercury) for d in the equation as follows:

$$p = 5 \times 13.6, \text{ or } 68 \text{ grams per square centimeter.}$$

If the pressure of a gas is relatively high, it is commonly measured by means of a device known as a closed manometer tube. This device resembles an open manometer tube, except that the longer arm of the tube is closed. When no pressure except atmospheric pressure is exerted upon the mercury in the tube, the mercury stands at the same level in both arms. When the shorter arm is attached to a vessel containing gas under pres-

PRESSURE UPON A CONFINED GAS

sure, the mercury falls in the shorter arm and rises in the longer arm, compressing the trapped air in accordance with Boyle's law. Thus the length of the column of trapped air indicates the pressure of the gas. In order to calculate this pressure, we read a scale on the tube that is calibrated to show grams per square centimeter or pounds per square inch.

Outside the laboratory the pressure of a gas is commonly measured by means of a pressure gauge of the Bourdon type, already described. This gauge, which is calibrated to show pounds per square inch, is widely used on boilers to show the pressure of steam and also on ordinary compression tanks at automobile service stations to show the pressure of air.

The pressure of air in an automobile tire or bicycle tire is measured by a small device known as a tire gauge. This device consists of a rubber tube that is closed at the top but open at the bottom for the admission of air as shown in Figure 48. Surrounding the rubber tube is a coiled spring that is attached at the bottom but is free to move at the top. Surrounding the spring is a movable metallic tube that is provided with a scale calibrated in pounds per square inch. When the gauge is pressed against the valve of a tire, air from the tire causes the rubber tube and the surrounding coiled spring to elongate and push the metallic tube outward. The greater the pressure exerted by the air in the tire, of course, the farther outward the metallic tube moves. The tire gauge, like the Bourdon gauge, registers zero when only the atmospheric pressure is acting, and therefore measures only the pressure above atmospheric pressure.

Occasionally scientists are concerned with the total pressure of a confined gas, in which case they add the atmospheric pressure to the pressure indicated by the manometer tube or pressure gauge. Such a pressure, known as absolute pressure, means the complete pressure above a vacuum. When the pressure of a confined gas is the same as atmospheric pressure, it is referred to as a pressure of one atmosphere.

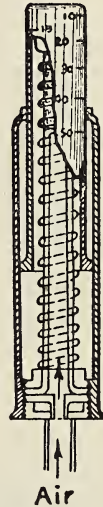


Fig. 48. A tire gauge.

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Measuring the volume of a gas. Occasionally it is necessary to measure the volume of a gas which flows from a container, as is done in measuring natural or artificial gas supplied to homes for heating and illuminating purposes. In such a case the volume,

or quantity, of the gas depends upon the density, but the density according to Boyle's law is directly proportional to the pressure. Therefore gas companies seek to maintain a constant pressure of gas and thus to avoid variation in density.

The movement of gas is measured by a device known as a gas meter, which registers the flow in cubic feet. This device,

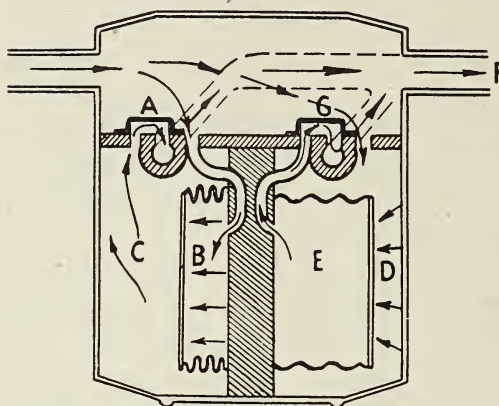


Fig. 49. As indicated by the arrows above, the gas flows into a gas meter from the left, operates the registering mechanism, and leaves at the right.

as shown in Figure 49, consists of two bellows separated by a diaphragm. The gas enters through valve A, fills compartments B and C, and pushes gas from compartments D and E through opening F to the outside. Then valve A closes and gas enters through valve G, fills compartments D and E, and pushes gas from compartments B and C through opening F. As these alter-

nate movements continue, the vibrations of the diaphragm operate a set of gears that rotate the hands of dials as shown in Figure 50. The dial marked 100,000 registers up to 100,000 cubic feet; the dial marked 10,000 registers up to 10,000 cubic feet; and the dial marked 1000 registers up to

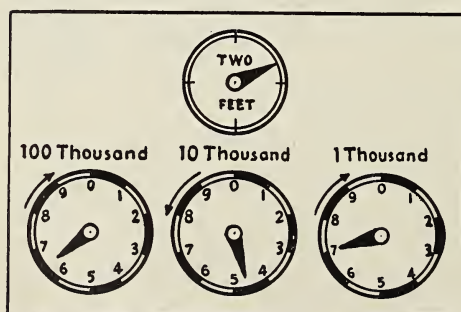


Fig. 50. What reading is shown by the above gas-meter dials? How can you explain the reading?

PRESSURE UPON A CONFINED GAS

1000 cubic feet. Thus if the hand is past 6 on the 100,000 dial, past 4 on the 10,000 dial, and past 7 on the 1000 dial, the combined reading is 60,000 cubic feet, plus 4,000 cubic feet, plus 700 cubic feet, or 64,700 cubic feet. The hands on some of the dials turn clockwise, and the hands on other dials turn counterclockwise. The dial marked "two feet," which is usually found above the other dials, is merely used in testing and hence is not considered in reading the quantity of gas consumed.

ANSWER THESE QUESTIONS

1. How is Boyle's law commonly stated in its simplest form for purposes of study? What equation may be used to show the relation between volume and pressure?

2. How is Boyle's law stated to show that the relation between the volume and pressure of a gas is constant? What is the meaning of *constant*?

3. How is Boyle's law concerned with density? How may the statement of the law be extended to show this relationship?

4. How does the Cartesian diver illustrate Boyle's law? What other principles of physics does the diver illustrate?

5. What interesting experiment in the laboratory enables a person to plot a curve in accordance with Boyle's law?

6. What is a vacuum pump? How does the pump operate? Why does it never produce a complete vacuum?

7. How does a vacuum cleaner resemble a vacuum pump? For what purposes is a vacuum cleaner used?

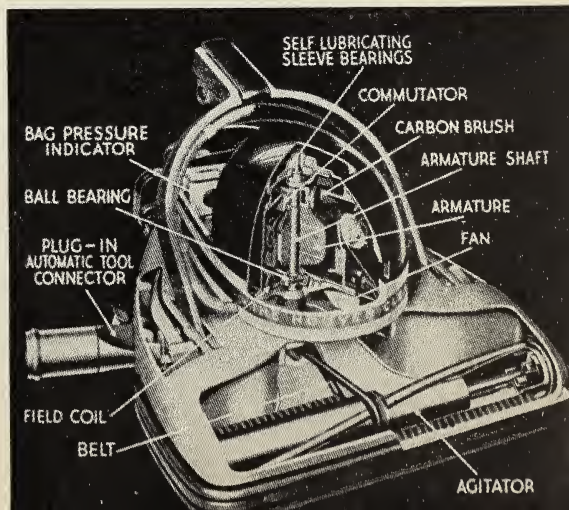
8. What is a compression pump? How does this pump operate?

9. What are Westinghouse air brakes? What are the essential parts of an air-brake system? How do the brakes work to regulate the speed of a train? Why do they work when a train breaks in two?

10. How is the pressure of a light gas commonly measured in the laboratory? How is the pressure of a heavy gas measured?

11. How is the pressure of a gas commonly measured outside the laboratory? What are the essential parts of a tire gauge?

The modern vacuum cleaner, which somewhat resembles a vacuum pump in operation, is a practical application of Boyle's law.



HOW MAN CONTROLS LIQUIDS AND GASES

SOLVE THESE PROBLEMS

A

1. If 100 cu. ft. of air exerts a pressure of 50 lb. per square inch and the temperature remains constant, how much must the volume be decreased to secure a pressure of 80 lb. per square inch?
2. If 500 cu. ft. of gas exerts a pressure of 120 lb. per square inch and the temperature remains constant, what pressure will the gas exert if the volume is increased to 900 cubic feet?
3. A tank whose volume is 100 cu. ft. is filled with air at the ordinary atmospheric pressure of 14.7 lb. per square inch. How much must the volume be decreased to obtain a pressure of 60 lb. per square inch if the temperature remains constant?
4. A tank with a capacity of 2.4 cu. ft. is filled with oxygen under a pressure of 1200 lb. per square inch. How many cubic feet of oxygen will the tank deliver at a pressure of one atmosphere if the temperature remains constant?
5. An automobile tire has a capacity of 2000 cubic inches. How many cubic inches of air at a pressure of one atmosphere are required to inflate the tire to a pressure of 30 lb. per square inch, according to a pressure gauge if the temperature remains constant?
6. The air in a storage tank at an automobile service station, according to the pressure gauge, exerts a pressure of 100 lb. per square inch. What is the absolute pressure of the air in the tank?
7. An acetylene gas tank with a capacity of 3 cu. ft. is filled with gas at a pressure of 2000 lb. per square inch, according to the pressure gauge. How many cubic feet of gas have been used when the pressure-gauge reading is 840 lb. per square inch if the temperature remains constant?

B

8. An air-storage tank with a capacity of 1000 cu. ft. is filled with air at a pressure of 100 lb. per square inch, according to the pressure gauge. How many automobile tires with a capacity of 1500 cu. in. each may be filled from the tank if the tires are inflated to a pressure of 30 lb. per square inch, according to a tire gauge, and the temperature remains constant?
9. An air-storage tank contains 1000 cubic feet. How many cubic feet of air at atmospheric pressure are required to fill the tank to a pressure of 80 lb. per square inch, according to the pressure gauge, when the mercurial-barometer reading is 30 inches and the temperature remains constant?

SUMMARY

10. A tank with a capacity of 2 cu. ft. is filled with oxygen under a pressure of 1000 lb. per square inch, according to the pressure gauge. A second tank with a capacity of 3 cu. ft. is filled with oxygen under a pressure of 800 lb. per square inch. The two tanks of oxygen are then connected so that the contents may flow freely from one tank to the other. What is the final pressure of the oxygen if the temperature remains constant?

SUMMARY

Every liquid exerts downward, sidewise, and upward pressure because of its own weight. Pressure refers to force per unit area. The downward pressure is directly proportional to the depth and density of the liquid and acts independently of the shape and area of the container. The sidewise pressure is determined in the same manner as the downward pressure except that the pressure is calculated on the average height of the liquid rather than on the full height of the liquid. At any point within a liquid the downward, sidewise, and upward pressures are equal. The total force exerted by a liquid because of its weight is equal to the area over which the pressure is exerted times the pressure.

Pascal's law explains that the pressure exerted anywhere on a confined liquid is transmitted undiminished in all directions. Through the operation of this law a small force applied to a small area of liquid results in a large force upon a large area of the liquid. The force applied to a small piston divided by the area of the piston equals the resulting force on the large piston divided by the area of the large piston.

Archimedes' principle explains that the buoyant force of a liquid is exactly equal to the weight of the liquid displaced. When an object sinks, the apparent loss of weight is equal to the weight of the displaced liquid. When an object floats, the same condition prevails except that its apparent loss of weight equals its weight in air. The buoyant force of water helps to explain the use of ships and boats, including submarines.

Specific gravity is the ratio of the weight of a body in air to the weight of an equal volume of water. To find the specific gravity of an object, one must weigh the object in air, find the

HOW MAN CONTROLS LIQUIDS AND GASES

weight of an equal volume of water, and divide the weight of the object in air by the weight of the equal volume of water. To find the weight of the equal volume of water in the experiment, he must apply Archimedes' principle; that is, he must subtract the weight of the object in water from the weight of the object in air. The specific gravity of a liquid is usually found by means of a specific-gravity bottle or an instrument called a hydrometer, of which there are several kinds.

Atmospheric pressure is caused by the weight of air and is commonly measured in pounds per square inch or in the number of inches or centimeters to which a column of mercury rises in a vacuum. Under standard conditions at sea level atmospheric pressure is 14.7 pounds per square inch or 30 inches or 76 centimeters of mercury. Atmospheric pressure is measured by an instrument known as a barometer, which is calibrated in inches or centimeters of mercury. The barometer is extensively used in predicting weather conditions because a falling barometer usually precedes and hence indicates a storm and a rising barometer usually precedes fair weather.

The buoyancy of air, which corresponds to the buoyancy of water, enables man to use airplanes. In building airplanes, he must seek to cut down the resistance of air and at the same time take advantage of the buoyancy of air. The lift of an airplane depends upon Bernoulli's principle, which explains that the pressure of a fluid decreases as the velocity increases, and increases as the velocity decreases. Thus the pressure is lower upon the curved upper surface of the wing of an airplane than upon the flat lower surface, and the resulting difference in pressure is sufficient to hold the airplane aloft in flight.

Boyle's law states that if the temperature of a confined gas remains constant the volume of the gas is inversely proportional to the pressure. Expressed in another form, the law states that if the temperature of a confined gas remains constant the pressure of the gas multiplied by the volume is constant. When the density of the gas is considered, the law states that the pressure of the gas is directly proportional to the density.

INVESTIGATIONS

What are the essential parts of a submarine that enable it to rise and sink?

Why is it essential to establish a high waterhead in supplying water from a reservoir or water tower?

How does Pascal's law play an important part in safety on street and highway?

Why is it easier for a swimmer to float on the surface of the ocean than on the surface of a fresh-water lake?

How does Boyle's law help to explain the process of inhaling and exhaling in breathing?

Why is the specific gravity of an automobile battery greater when it is fully charged than when it is partially charged?

Theoretically is an airplane buoyed up more by the air on a rainy day than on a clear day?

What is a fairly high reading and what is a fairly low reading on a barometer?

SOLVE THESE PROBLEMS

1. If the density of sea water is 64 lb. per cubic foot, what force is exerted upon one square foot of the bottom of a boat when the bottom is 25 ft. below the surface of the ocean?

2. The diameter of the small piston of a hydraulic press is 2 in., and the diameter of the large piston is 10 inches. What load on the large piston can be lifted with a force of 50 lb. applied upon the small piston?

3. If a body contains 2 cu. ft. and weighs 1200 lb. in air, what does it weigh in water when the density of water is 62.4 lb. per cubic foot?

4. A body weighs 500 g. in air and 300 g. in water. What is the specific gravity of the body?

5. If a barometer reads 29.6 in. of mercury, what is the atmospheric pressure in pounds per square inch?

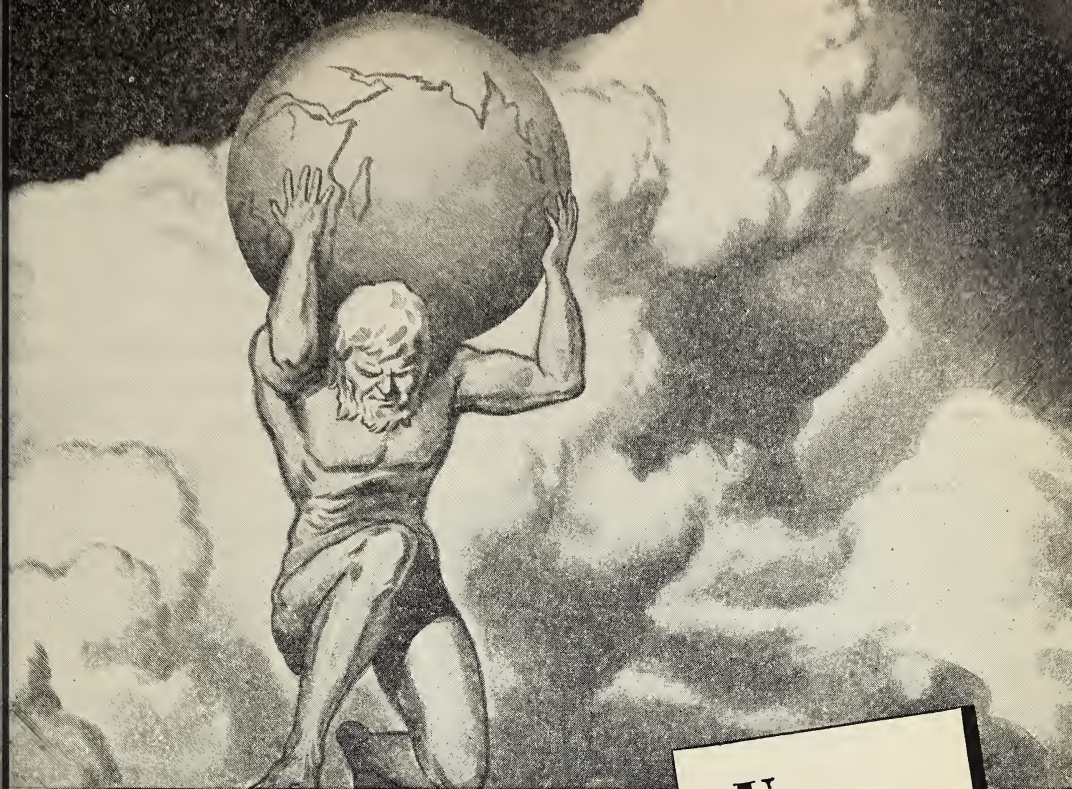
6. If 1000 cu. ft. of air at a pressure of one atmosphere is compressed into a container containing 50 cu. ft., what is the pressure of the air in the container when the temperature remains the same?

INVESTIGATIONS

1. Punch a small hole in the bottom of a tall tin can and push the bottom into a vessel of water. Compare the height to which the water spouts through the hole with the distance from the bottom of the can to the surface of the water.

HOW MAN CONTROLS LIQUIDS AND GASES

2. Compare the water pressure at a faucet in the basement of your home with the pressure at a faucet on the second floor.
3. Inspect a barber's chair to find out how the barber is able to raise an occupant in the chair by exerting a small force on a lever with his hand or foot.
4. Lift a heavy stone from the bottom of a swimming pool and observe the apparent weight of the stone under the water and its real weight out of the water.
5. Compare the specific gravity of the following liquids: whole milk, skimmed milk, and cream.
6. Examine a weather chart and try to predict the weather for your community.
7. Exhaust the air from a set of Magdeburg hemispheres and try to pull them apart.
8. Notice water boiling in a glass container and see where the vapor bubbles are largest.



According to a Greek myth, ancient Atlas was condemned to support the earth upon his shoulders. Such an idea seems strange in the light of modern understanding of the universe.

UNIT THREE

Exploring the Universe of Force

KNOWLEDGE REPLACES MYTHS

According to an old Greek myth that you may have read many times, ancient Atlas, conquered by his foe, was condemned to support the earth upon his shoulders. While reading this story, you may have wondered why the Greeks conceived such an idea—why they ever thought of a man supporting the earth. The explanation is that they knew little about the forces acting in the

EXPLORING THE UNIVERSE OF FORCE

universe, and they consequently attributed these forces to gods and goddesses and to numerous other characters with superhuman qualities. Thus, not knowing how the earth was supported, they created Atlas, endowed him with superhuman power, and put the earth upon his shoulders.

It is not surprising that ancient people were puzzled about forces, because forces are difficult to visualize. Nobody ever sees a force directly; he only observes its results. However, from these results he can determine its point of application, its direction, and its magnitude. For example, a person never sees the force that propels an automobile, but he can tell from what happens that the force is applied to the gears, that it moves the automobile forward or backward, and that it enables the automobile to travel at a certain rate of speed. All these results enable him to make an analysis of the force indirectly.

Much of the progress of man depends upon the uses which he makes of the forces around him. In many instances forces left uncontrolled are harmful; but once harnessed they become very helpful. An illustration is the force of the raging water of a river that comes tearing down a valley, taking people's lives, carrying away homes, washing away soils, and spreading other forms of destruction. Once a huge dam has been built across a river, the force of the water becomes a great asset to man. Instead of taking lives and spreading general destruction, it provides a steady water supply and generates electricity to serve man in a variety of ways, and thus to make for better living.

The purpose of this unit is to help you explore the forces that work in your physical environment, and to point out some of the ways in which these forces influence your behavior day after day. As you pursue your work, you will observe how forces originate, what measures are employed in controlling them, and what techniques are used in measuring them. This study should give you a better understanding of forces in your environment and enable you to make intelligent use of them in everyday life. Specifically, the major problems that you will consider are enumerated on the following page.

AREAS OF STUDY

1. *How does molecular action help to account for certain forces?*
2. *What forces are associated with molecular attraction?*
3. *How are objects affected by the force of gravity?*
4. *How is the magnitude of two or more forces determined?*
5. *How may accelerated motion be calculated?*
6. *What is the significance of Newton's laws of motion?*
7. *What forces affect an airplane in flight?*
8. *What forces act on a swinging pendulum?*

AREA ONE

How Does Molecular Action Help to Account for Certain Forces?

Several times in our work in physics thus far we have considered how the molecular theory helps to explain the behavior of matter. We have learned that all forms of matter—solids, liquids, and gases—are composed of molecules that are in constant motion. In a solid these molecules are close together and restricted in their motion; in a liquid they are farther apart and less restricted in their motion; and in a gas they hold together loosely and have great freedom of motion. Now let us consider some of the things that happen as a result of molecular action.

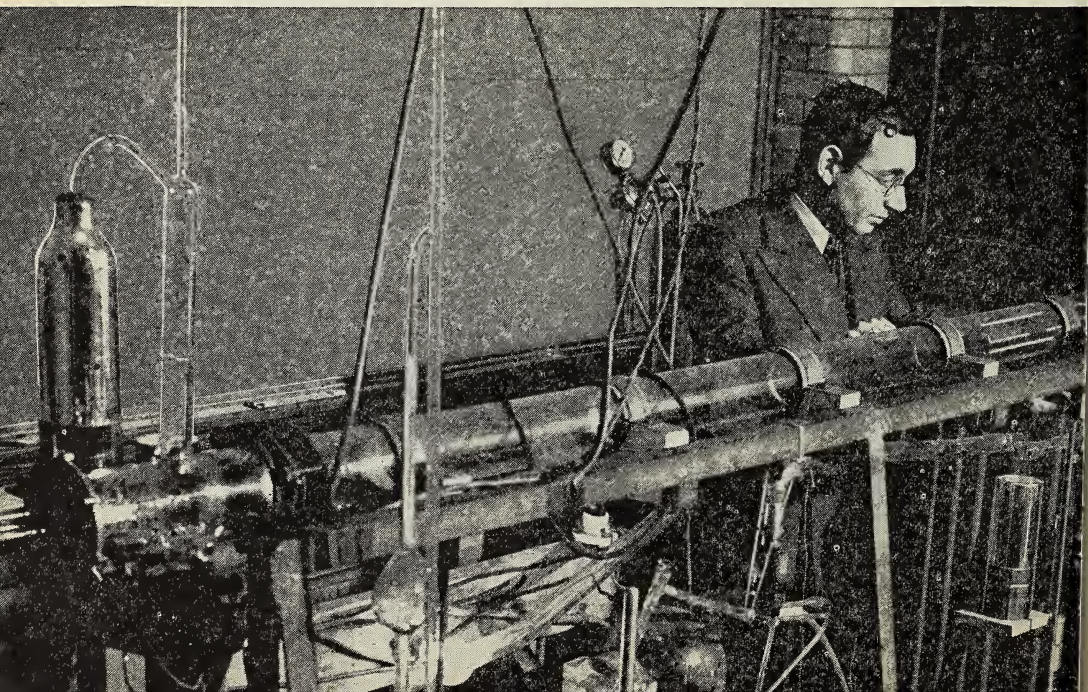
The Brownian movement. From a general understanding of the molecular theory we might assume that the movement of molecules is regular and balanced, but as a matter of fact it seems to be irregular and unbalanced. As the molecules collide with one

EXPLORING THE UNIVERSE OF FORCE

another they appear to move in varying directions and through varying distances, thus following haphazard paths. If we were to represent in a drawing the paths followed by molecules in their motion, we should have a jagged pattern somewhat resembling a crazy quilt. This movement of molecules was discovered in 1827 by a botanist named Brown and has come to be known as the Brownian movement. We may see the effects of the Brownian movement by observing through a microscope a tiny particle of matter suspended in water. The particle appears to dance in the water, showing that it is being bombarded by the surrounding molecules. If the bombardments were simultaneous on all sides, their effects would be neutralized and the particle would remain still. The fact that the particle dances shows that at one instant it is being bombarded more on one side than on the other and that at the next instant the direction of the bombardment is reversed. The Brownian movement offers an excellent example of physical behavior from which the scientist may draw tentative conclusions. Even though he cannot observe molecules, he may perform experiments to determine their movement and hence draw tentative conclusions concerning molecular forces.

The scientist in this picture is performing an experiment before a class in college to illustrate the behavior of molecules. Many experiments of this nature are performed in college and industrial laboratories where the necessary equipment is available.

L. H. Miller



The process of diffusion. One of the processes which results from molecular action is a mixing of the molecules of two or more substances. This process is known as diffusion. It is most noticeable in gases, less noticeable in liquids, and still less noticeable in solids. We may illustrate the diffusion of gases by inverting a bottle of hydrogen and placing it upon a bottle of carbon dioxide, as shown in Figure 51. The density of the hydrogen is less than the density of the carbon dioxide, but despite this difference in density some of the hydrogen moves downward and mixes with the carbon dioxide in the lower bottle and some of the carbon dioxide moves upward and mixes with the hydrogen in the upper bottle. This same process helps to explain why the odor of cooking food comes to us through the air.

We may illustrate the diffusion of liquids by putting water in a vessel and placing a layer of ether over the top. The density of ether is less than the density of water, but despite this difference in density some of the ether moves into the water and some of the water into the ether. We may also illustrate diffusion by dropping a particle of indigo into a small vessel of water. The indigo begins to color the surrounding water and then gradually spreads to all parts of the liquid. A similar process of diffusion occurs whenever we drop a lump of sugar into a cup of coffee or a cup of tea.

We may illustrate the diffusion of solids by placing a thin gold leaf between two pieces of lead. If we allow the materials to stand for several months, small particles of gold penetrate the lead and small particles of lead penetrate the gold.

One important form of diffusion is osmosis, which helps to explain how the cells of plants and animals take in food. In the case of osmosis diffusion takes place through a membrane which allows the molecules of one substance to pass through but few of the molecules of the other. Therefore the transfer is largely in one direction. To illustrate, if we put any dried fruit such

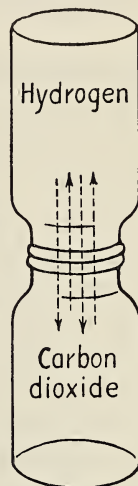


Fig. 51. The arrows indicate flow of gases.

EXPLORING THE UNIVERSE OF FORCE

as prunes or raisins into a dish of water, some of the water passes through the skin and fills out the fruit, but little of the sugar content of the fruit passes into the water. In many instances, when water passes into other liquids by means of osmosis, it sets up a pressure known as osmotic pressure, that may be sufficient to raise the level of the liquid several feet.

The molecular theory and pressure. As we have already learned, the molecular theory helps to account for the pressure of gases, and consequently for the forces that operate as a result of the pressure. Whenever we pump air into an automobile tire, for example, we put into the tire more molecules of the gases that make up air, or increase the density of the air. The molecules, having less space in which to move, then collide more often with one another and with the walls of the tire, and this increased activity sets up a greater pressure. If we put in twice as much air, we double the density and consequently double the bombardment of molecules. The doubled bombardment doubles the pressure and thereby doubles the force within the tire tending to push the walls outward. The molecular action of solids and liquids sets up no such pressure because their molecules are less mobile and have less tendency to fly out into space.

Much study has been given in recent years to the speed with which molecules move, and many interesting calculations have been made. On the basis of these calculations, a molecule of oxygen at freezing temperature is supposed to travel at a rate of 1400 feet per second, and a molecule of hydrogen at 5600 feet per second. The rate of speed seems to be greatly affected by temperature, the rate increasing as the temperature increases and decreasing as the temperature decreases.

ANSWER THESE QUESTIONS

1. What is meant by the Brownian movement? What kind of paths do molecules follow in these movements? How may we observe the effects of molecular motion?
2. What is meant by diffusion? What simple experiments may we perform to illustrate the diffusion of gases, liquids, and solids?

FORCES AND MOLECULAR ATTRACTION

3. How does osmosis differ from ordinary diffusion? Why is osmosis especially important to plants and animals?

4. How does the molecular theory help to account for the pressure of confined gases? What force is set up whenever an automobile tire is inflated?

5. How fast are molecules supposed to travel? How is the rate of speed affected by changes in temperature?

AREA TWO

What Forces Are Associated with Molecular Attraction?

The molecular theory, besides indicating that molecules are in constant motion, also indicates that they have attraction for one another. In general, the attraction is greatest in solids, which accounts for the comparatively rigid nature of solids, and least in gases, which accounts for the expansive nature of gases. Let us now see what forces depend for their operation upon the attraction of molecules for one another.

What is meant by cohesion and adhesion? Two forces that may be explained solely upon the basis of molecular attraction are cohesion and adhesion. Cohesion is the force resulting from the attraction of like molecules, or molecules of the same substance. This force tends to hold the parts of the substance together, sometimes with great tenacity, as in the case of iron. In order to break a piece of iron, a person must apply a force greater than the cohesive force of the molecules. Adhesion, which is similar to cohesion, is the force resulting from the attraction of unlike molecules, or molecules of different substances. On the basis of this force chalk clings to a blackboard when it is used in writing.

Since cohesion refers to the force caused by the attraction of like molecules and adhesion to the force caused by the attraction of unlike molecules, the forces are often in conflict. Such is the case when mercury is poured upon glass, but no mercury clings

EXPLORING THE UNIVERSE OF FORCE

to the glass because the force of cohesion is stronger than the force of adhesion. On the other hand, when a postage stamp is placed on a letter, the stamp clings to the letter because the force of adhesion is stronger than the force of cohesion.

FORCES RELATED TO STRUCTURE

Cohesion and the property of elasticity. The cohesion of a substance determines its elasticity, or the property of returning to its original shape once it has been distorted by an outside force. Ordinarily we think of rubber as elastic because we can readily distort it and it tends to return to its original shape. According to the science of physics, however, the greater the force required to distort a substance, provided the substance returns to its original shape or position, the greater is the elasticity of the substance. On the basis of this scientific definition, steel has greater elasticity than rubber, provided the steel returns to its original shape. When an object is distorted by an outside force to a point where it fails to return to its original shape, it is said to have exceeded its elastic limit.

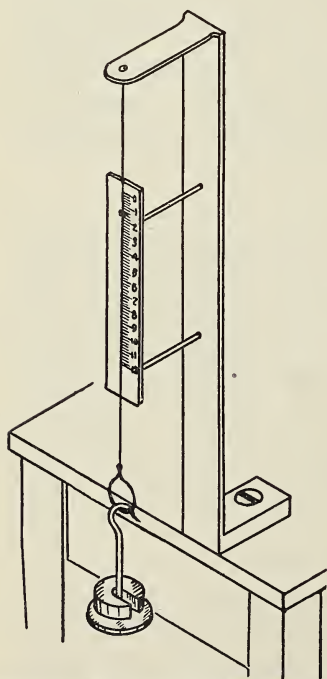


Fig. 52. This apparatus measures the elongation, or stretching, of wire caused by the suspension of weights.

What is the meaning of Hooke's law?

One of the first persons to experiment with the elasticity of objects was an English scientist by the name of Hooke. This scientist found that if we hang weights upon a suspended wire and attach a pointer to show the elongation of the wire as shown in Figure 52, we find that the elongation is directly proportional to the weight. In other words, within the elastic limit, if we double the weight, the elongation is twice as great; if we

FORCES AND MOLECULAR ATTRACTION

treble the weight, the elongation is three times as great, and so on. In scientific language Hooke's law is commonly stated as follows: *Within the elastic limit, the elongation of an object is directly proportional to the stretching force.*

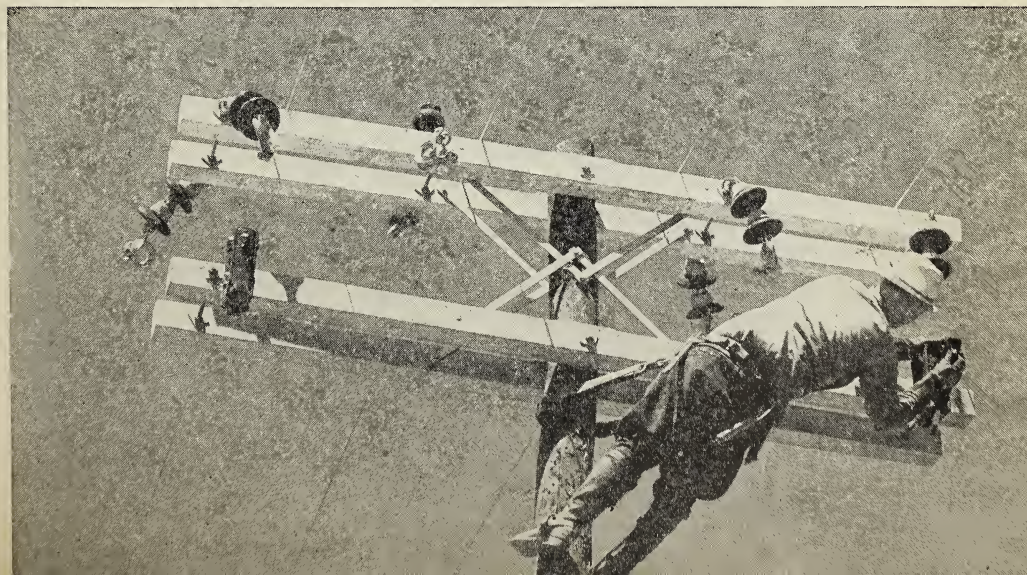
A common device that operates on the principle of Hooke's law is the spring balance in Figure 53. This balance consists of a coiled spring that elongates when objects are attached to the hook at the bottom. As the spring elongates, it moves a pointer down from zero on the scale at the front and indicates the weight of the object. When an object weighs one pound the spring elongates a certain distance, and when the object weighs ten pounds it elongates ten times this distance. Thus it provides an accurate measurement, the elongation being directly proportional to the weight. A stop, or safety device, at the bottom prevents it from stretching beyond the elastic limit. The spring balance is widely used, especially in homes, because it is relatively inexpensive and occupies little space. In food stores it is used in weighing such materials as vegetables and fish, and on farms for weighing such materials as butter and milk. On the whole, however, it is less widely used than the beam balance which is usually more convenient.



Fig. 53. A spring balance.

Telephone and telegraph wires are always under tension because they are stretched tightly from one pole to another. Sometimes, when they are tossed about by strong winds or are heavily coated with ice, they break because their elastic limit is exceeded.

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EXPLORING THE UNIVERSE OF FORCE

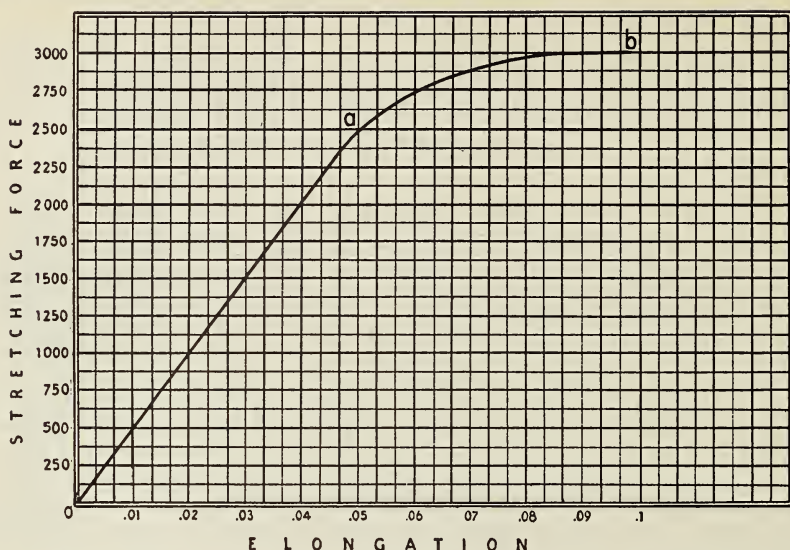


Fig. 54. The above curve illustrates the operation of Hooke's law. The elongation increases evenly with the stretching force as far as *a*, the elastic limit. Beyond *a* the elongation increases more than the stretching force, finally terminating at *b*, the breaking point.

Frequently in testing the tensile strength of objects according to Hooke's law, we may wish to plot our findings as shown in Figure 54. If we study this curve we find that up to a certain point, indicated by *a*, the elongation is directly proportional to the weight, but from that point on the elongation increases in relation to the weight and finally gives way entirely at point *b*. All this indicates that up to point *a* the object would return to its original shape if the weight were removed, but beyond point *a* the object would not return to its original shape because the elastic limit has been exceeded.

Stress in relation to elasticity. When a force acts upon an object, tending to distort its shape, it causes *stress*. By stress we mean the force per unit area, which we find by dividing the total force at work by the area of a cross section of the object through which it works. Thus if a force of 100 pounds pulls upon a wire with a cross section of 0.0625 square inch, we divide 100 by 0.0625 and obtain a stress of 1600 pounds per square inch.

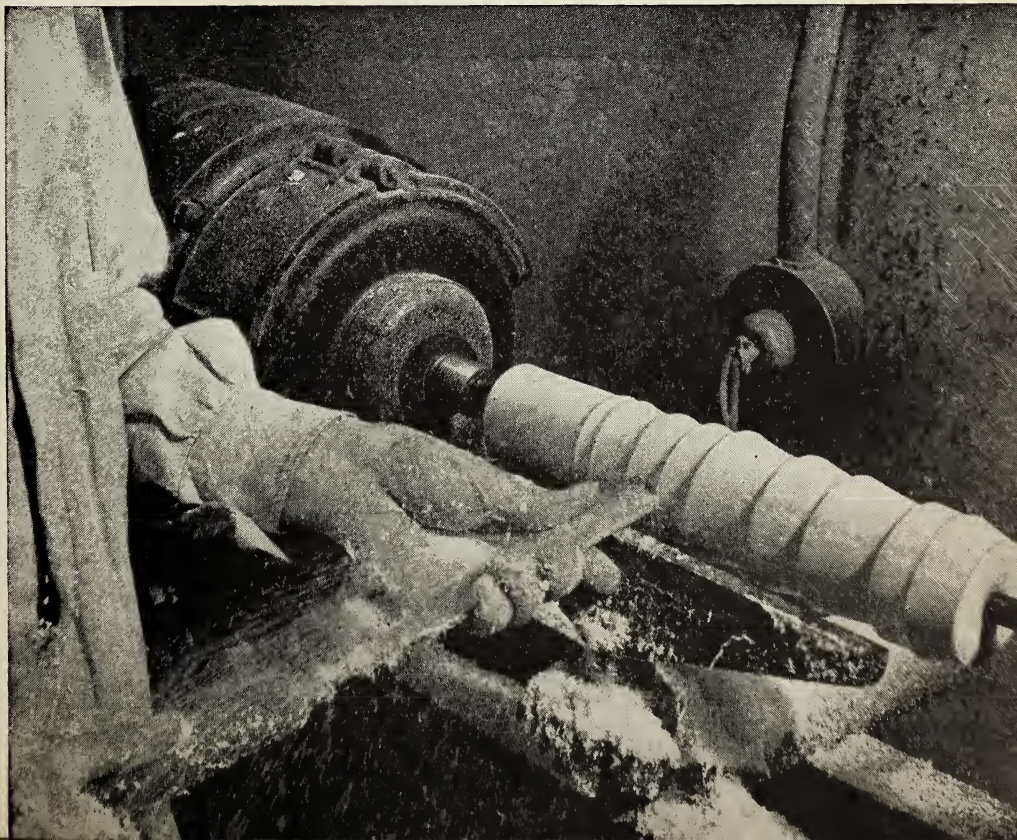
FORCES AND MOLECULAR ATTRACTION

Stress may assume any one of several forms, depending upon the way in which a force is applied. If a force tends to pull the molecules of an object apart, the resulting stress is called a *tension*, and the object is said to be under tension. If a force tends to crowd the molecules closer together, the resulting stress is called a *compression*, and the object is said to be under compression. If a force tends to cause the molecules to slide over one another, the resulting stress may be either *shearing* or *twisting*, depending upon the particular form which the force takes.

The operation of stress upon an object causes *strain*. By strain we mean the relative deformation of an object, or the change that the object undergoes as a result of stress. When a heavy object is suspended by a wire, the resulting stretching, or elongation, of the wire is called the strain. This can be measured by dividing the total elongation of the wire by its total length. If the wire is five feet long and the pull of a weight causes it to stretch 0.4 inch, we divide 0.4 by 5 to determine the elongation

This picture illustrates two common kinds of stress: twisting stress caused by the force that rotates the spindle and shearing stress caused by the workman's chisel.

L. H. Müller



EXPLORING THE UNIVERSE OF FORCE

per unit length. From the foregoing we see that stress is a force and strain is the deformation produced by the force. Thus a tension stress produces a tension or tensile strain; a compression stress produces a compression strain; a shearing stress produces a shearing strain; and a torsion stress produces a torsion strain. If we were to determine the relation between a stress and a strain, we should find that the stress is directly proportional to the strain and that, for any given elastic object, the ratio of stress to strain is constant.

The question of stress is especially important to engineers in choosing materials for the construction of buildings, bridges, and machines. They must keep in mind the elastic limit of materials, for they know that beyond the elastic limit deformation of the materials takes place rapidly and that a point is soon reached at which the materials break or give way completely. The stress that may be applied to a material without deforming it permanently or causing it to break is known as the working-unit stress. The stress that causes the material to give way or to break is known as the ultimate strength. Both the working-unit stress and the ultimate strength have been determined by experiment for many important materials and tabulated in tables for the convenience of engineers. Both are expressed in pounds per square inch. To apply them to the cross section of any material under tension, compression, or shear, we multiply the figures given for the material by the area of the cross section. The ratio of the ultimate strength to the working-unit stress is known as the factor of safety, which may be expressed as follows:

$$\text{Factor of safety} = \frac{\text{ultimate strength}}{\text{working-unit stress}}.$$

In actual construction the factor of safety is kept relatively low when the stress is steady as in buildings, somewhat higher when the stress varies as in bridges, and relatively high when the stress is frequently repeated as in machines. To illustrate, the factor of safety for structural steel used in buildings is four, for steel used in bridges it is six, and for steel used in machines it is ten.

Other properties explained by molecular attraction. Besides explaining elasticity, molecular attraction helps to explain several other properties of matter, including malleability, ductility, and hardness. A substance is malleable when it can be hammered into any desired shape without breaking the molecules apart. An excellent example of a malleable substance is gold, which can be hammered into an extremely thin leaf. The test of malleability is the thinness of the sheet into which a substance may be hammered. A substance is ductile when it can be heated and drawn into a fine wire or thread. An excellent example of a ductile substance is iron, which, when heated, can be drawn through a die and made into different-sized wires. Another illustration of a ductile substance is tungsten, which can be drawn into fine filaments for incandescent lamps. The test of ductility is the fineness of the wire into which a substance may be drawn. A substance is hard when it is sufficiently rigid to cut or scratch another substance. On this basis a diamond is harder than glass, and glass is harder than steel. Some metals can be hardened by a process of heating and sudden cooling, which rearranges the molecules. Occasionally, however, this rearrangement of molecules results in brittleness. This can be overcome by a slow process of cooling known as tempering.

Stresses upon materials used in industry. Since, as we have learned, molecular attraction accounts for certain outstanding properties in matter, scientists perform many experiments in laboratories to modify the attraction. For example, if a metal lacks certain properties to make it especially well suited to industry, the scientists form alloys of the metal by adding other metals in the process of manufacture to impart the necessary qualities. One of the chief metals with which they work is iron, because iron possesses excellent basic properties and yet lacks the necessary strength and hardness for certain types of construction. The alloys of iron are of many different grades, all being known as various grades of steel. One grade is especially well suited to one type of construction such as the building of railroad tracks, another grade to

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another type such as the building of bridges, and another grade to another type such as the making of gears or cutlery.

Other important alloys which scientists develop in their laboratories are the alloys of aluminum, two of the most common being duraluminum and magnalium. Aluminum, like iron, possesses excellent basic properties and is especially valuable because of its lightness; but it needs other properties to make it widely useful. The alloys of aluminum supply these deficiencies and thus produce materials widely used in the construction of airplanes, automobiles, and streamline trains and in the manufacture of such products as castings, carburetors, and the piston heads of internal-combustion engines.

Important copper alloys include brass and bronze, which like steel are made in many grades, and bearing metal, Monel metal, and German silver. These alloys supply materials widely used in the construction of airplanes, automobiles, radios, and electrical instruments and in the manufacture of such products as rainspouts, wire, money, and jewelry. Among other alloys that are widely used in industry are the alloys of tin, chief of which is solder formed by the addition of lead. This alloy is used in joining together pieces of metal, as the parts of tin cans.

Withstanding the stresses of an airplane. One of the greatest problems facing the scientist of modern times is the problem of securing suitable materials for the construction of airplanes. These materials, on the one hand, must be exceptionally strong because the airplane is subjected to a variety of stresses in flight. On the other hand, they must be relatively light in weight because the airplane depends upon the buoyancy of air. To solve this problem the scientist has turned to the field of metal alloys, testing first one alloy and then another. As a result, he has found the alloys best suited for the construction of the fuselage, the propeller, and other essential parts. Besides testing materials in this manner, he has also studied various types of assembling or bracing. Thus he has found methods of securing maximum strength with a minimum of materials.

FORCES AND MOLECULAR ATTRACTION

The fuselage, or hull, of an airplane is provided with a strong framework, consisting of a series of circular struts as shown in Figure 55 and two lengthwise trusses of one of the types shown

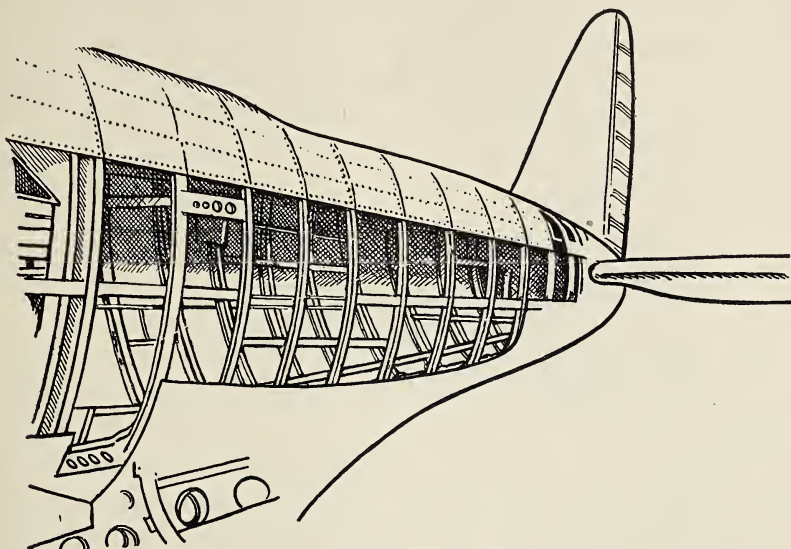


Fig. 55. This drawing shows the circular struts, or curved braces, in a fuselage.

in Figure 56. Each truss consists of two lengthwise pieces known as longerons, which extend the full length of the airplane, and struts, which extend either vertically or diagonally between the longerons. The truss is braced by tie rods as shown in the upper

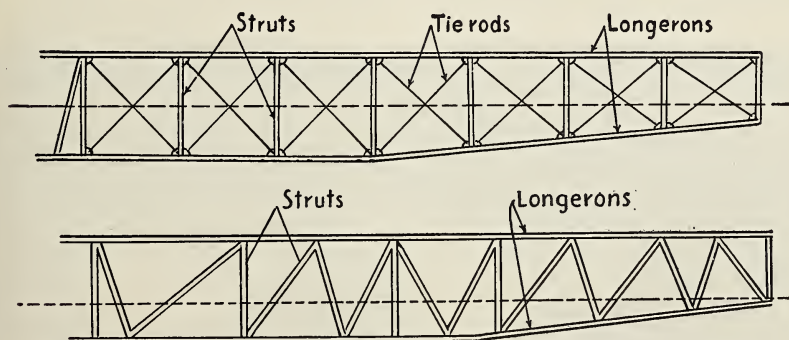


Fig. 56. This drawing shows two types of lengthwise trusses used in a fuselage.

EXPLORING THE UNIVERSE OF FORCE

drawing or by the slanting position of the struts as shown in the lower drawing. The framework is covered with an aluminum alloy as strong as steel but only about one-tenth as heavy as steel. Usually this alloy is coated with a thin sheet of pure aluminum, which helps to resist corrosion. The stabilizing units of the airplane, or the vertical section known as the fin and the horizontal section known as the stabilizer, attached to the fuselage at the rear, are made of the same materials as the fuselage.

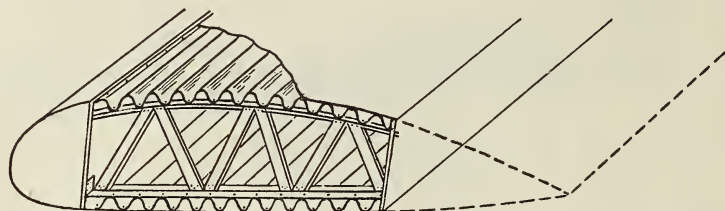
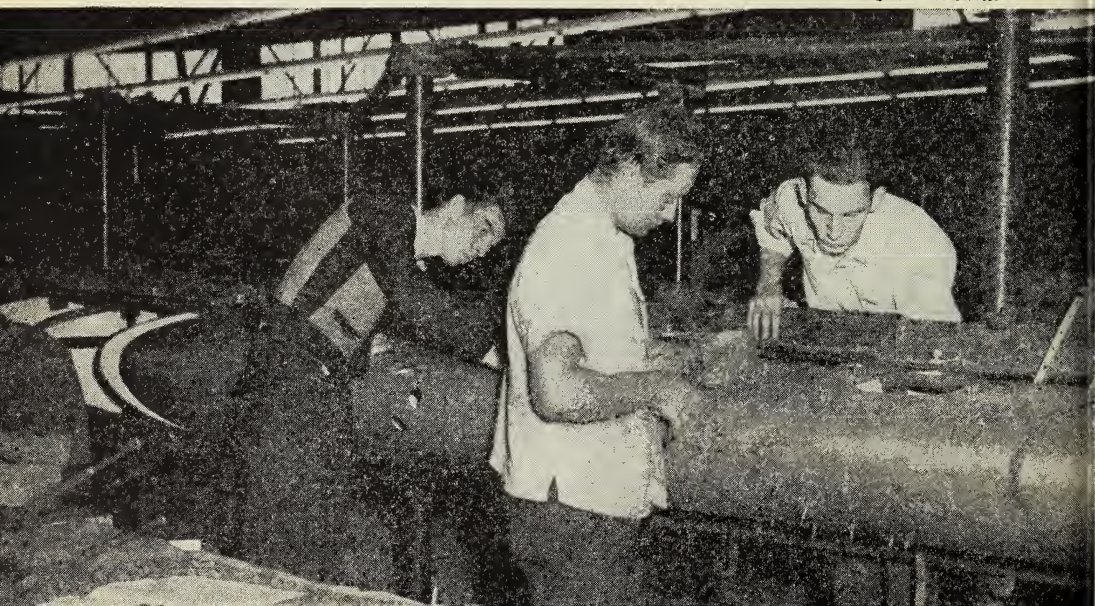


Fig. 57. The truss and corrugated metal covering which give strength to the wing.

The wings of an airplane have trusses that run crosswise, as shown in Figure 57, but no framework that runs lengthwise. The strength lengthwise is secured from the metal covering, which is corrugated to add to its rigidity. This covering usually consists of an aluminum alloy similar to that used on the fuselage, the surface being covered with a thin layer of pure aluminum that helps to resist corrosion caused by exposure to weather.

These workers in an airplane factory are assembling the model of a wing. Later this wing will be carefully tested in an air tunnel for its fitness as the wing of a bomber.

Goodyear News Service



FORCES AND MOLECULAR ATTRACTION

The engine mount, or tubular framework, to which the engine is attached as shown in Figure 58 is so constructed that it may be detached from the airplane. Thus the engine may be easily removed for repairs and another engine put in its place to keep the airplane in use. The mount is usually constructed of an alloy known as chrome molybdenum, which is noted especially for its strength. Rubber cushions between the engine and the mount help to absorb the vibrations of the engine.

The landing gear, which consists of the metal framework and wheels used in taxiing, is made especially strong to resist the sudden shock that occurs when the airplane first touches the ground in landing, and also to resist the shock that occurs when the brakes are applied to the wheels. This framework is usually made in tubular construction of various alloys such as steel and manganese bronze. Tie rods and huge shock absorbers help to protect the airplane from the stresses of landing and braking.

The propeller, because of its shape and rapid revolution, is probably subjected to greater stresses than any other part of an airplane. The hub in many instances is made of an alloy known as chrome vanadium steel and coated with cadmium. The blades are made of an aluminum alloy noted for its great strength. In other cases the complete propeller is made of steel.

The men who design the various parts of the modern airplane, the workers who assemble the parts into the finished product, and the pilots and mechanics who operate the planes must all be acquainted with the principles of physics. They must have a thorough knowledge of the physical forces that affect the flight of an airplane so that they may increase the usefulness of aviation.

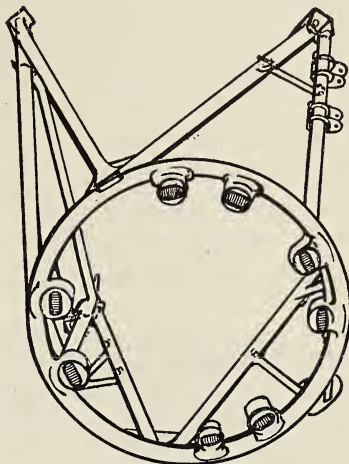


Fig. 58. The airplane engine is held in place by a framework similar to that above, known as the mount.

FORCES RELATED TO THE SURFACE OF LIQUIDS

What is meant by surface tension? Doubtless we have wondered many times how a beetle can walk upon water. We may have wondered, too, why a needle or safety-razor blade, if carefully placed upon the surface of water, will float. The explanation is that the force of cohesion, acting in the molecules of a liquid, sets up a tendency for the surface of the liquid to contract. This tendency, known as surface tension, causes molecules at the surface to form a covering for the liquid somewhat like a membrane.

To understand how surface tension works, let us compare the forces affecting two molecules of water, one beneath the surface and one at the surface, as shown in Figure 59. Molecule B,

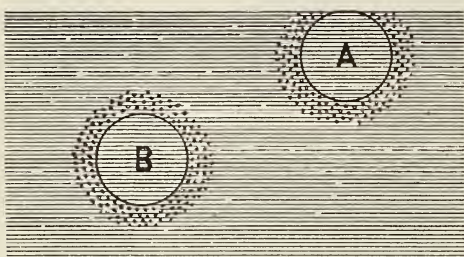


Fig. 59. How does the difference in the location of these molecules affect the forces acting upon them?

which is beneath the surface, is surrounded by molecules that tend to attract it equally from all directions. Molecule A, which is at the surface, on the other hand, has no molecules above, and consequently the molecules below tend to pull it downward. This pull from below the surface tends to crowd

the molecules at the surface closer together, causing them to form an elastic covering somewhat like a sheet of thin rubber.

Another interesting illustration of surface tension may be drawn from ordinary raindrops. Perhaps we have asked ourselves many times why raindrops are "round," and of course by *round* we mean *spherical*. The explanation is that surface tension tends to cause the surface of each drop to contract into the smallest possible area; and this area, as we have learned from geometry, is the surface of a sphere. When dropped through the air, other liquids tend to form the same shape. One interesting example is molten lead, which is dropped through the air in making bullets. From these illustrations, perhaps we can explain what happens when we blow soap bubbles.

FORCES AND MOLECULAR ATTRACTION

The surface tension varies with different liquids. Alcohol, for instance, has less surface tension than water. If we place two matches fairly close together in parallel positions upon the surface of water and allow a drop of alcohol to fall between them, they fly apart because the alcohol weakens the surface tension. If we place small shavings of camphor upon the surface of water, the camphor dissolves most rapidly where the edges of the shavings touch the water, thus lowering the surface tension near the edges and causing the shavings to dance about freely on the surface. If we cause a drop of soapy water to fall upon a surface wet with pure water, as a flat piece of glass, the pure water pulls away from the soapy water because the surface tension of the pure water is greater than that of the soapy water.

What is meant by capillarity? If we drop one end of an open glass tube of small bore into a vessel of water, we find that the level of the water rises in the tube a little above the level of the water outside the tube, as shown at the left in Figure 60. If we drop the same tube into mercury, however, we find that the mercury in the tube does not rise to the level of the mercury on the outside, as shown at the right in Figure 60. This tendency of the surface of liquids to rise or fall in small tubes is known as capillarity. The word *capillarity* comes from a Latin word meaning "hair," and hence small tubes such as those mentioned above are called capillary tubes. A liquid always rises in a tube when it wets the sides of the tube as in the case of water upon glass, and it falls in the tube when it does not wet the sides as in the case of mercury upon glass. The height

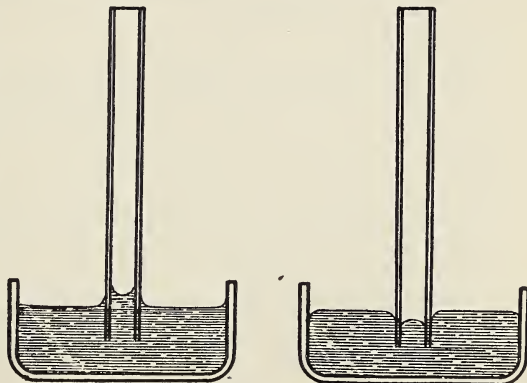


Fig. 60. This drawing shows how water rises by capillarity in the tube at the left and mercury falls in the tube at the right.

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to which a liquid rises or falls in a capillary tube is inversely proportional to the diameter of the tube. If a liquid rises six inches in a capillary tube of a certain diameter, it rises exactly three inches in a tube with a diameter twice as great.

Many illustrations of capillarity may be drawn from everyday life, such as the absorption of ink by a blotter and the rising of oil in the wick of a lamp. The process is of special importance in the field of agriculture because it explains the rising of water in soils. When the surface of soils is allowed to become hard, the water rises to the surface and evaporates into the air. By cultivation, however, farmers may reduce capillarity at the surface and thus hold the water in the subsoil where it is needed to carry nourishment by the process of osmosis to the roots of plants. Cultivation accomplishes this result because it separates the soil particles near the surface and makes it more difficult for water to pass from one particle to another.

ANSWER THESE QUESTIONS

1. What is meant by the force of cohesion? How does this force differ from the force known as adhesion?
2. How does cohesion help to explain the property of elasticity? Why may steel under certain conditions be said to be more elastic than rubber?
3. What is Hooke's law? How does the spring balance illustrate Hooke's law?
4. What is meant by stress? What are some of the principal forms of stress? What is the difference between stress and strain?
5. Why is the question of stress of special importance to engineers in the field of construction? How are they concerned with the elastic limit of materials? What is the difference between the elasticity of a material and its ultimate strength?
6. What other properties besides the property of elasticity does cohesion help to explain?
7. Why do scientists experiment extensively with alloys? What are some of the most helpful alloys that they have produced?
8. What twofold problem faces scientists in the construction of airplanes? How do they meet the problem in constructing the fuselage? the wings? the engine mount? the landing gear? the propeller?

FORCES AND MOLECULAR ATTRACTION

9. What is meant by the surface tension of liquids? How does surface tension help to explain why a beetle can walk upon water? How does it help to explain the shape of raindrops?

10. What is meant by capillarity? How does the height to which a liquid rises or falls vary with the diameter of the tube? Why is capillarity of special importance to farmers?

SOLVE THESE PROBLEMS

A

1. If a load of 20 g. causes the pointer of a spring balance to drop 5 mm. on the scale, how much of a load will cause it to drop 3 centimeters?

2. If a cylindrical rod 2 in. in diameter is under a tension of 5000 lb., how much is the stress?

3. If the rod in problem 2 is 36 in. long and elongates 0.05 in., how much is the strain?

4. If the elastic limit for hard steel is 50,000 lb. per square inch, will a force of 20,000 lb. suspended from a steel rod one inch in diameter cause the rod to exceed its elastic limit?

5. If the elastic limit of structural steel is 36,000 lb. per square inch, what force exerted upon a cylindrical rod 2 in. in diameter will cause the rod to reach its elastic limit?

6. If the ultimate compression strength of a certain wood is 8000 lb. per square inch, what is the factor of safety if a column 6 in. wide and 10 in. thick supports a load of 30,000 pounds?

7. How much higher does water rise in a capillary tube 0.1 mm. in diameter than in a tube 0.4 mm. in diameter?

8. If mercury falls 2 cm. in a tube 4 units in diameter, how far will it fall in a tube 6 units in diameter?

B

9. A wire of certain diameter withstands a pull of 3000 lb. before it breaks. How much would a wire of the same material withstand with twice the diameter? with one-half the diameter?

10. A wire 30 ft. long and 0.3 in. in diameter stretches 30 in. when a force of 3000 lb. is applied. What is the unit stress on the wire? What is the unit strain?

11. What is the breaking stress of a rod 0.85 in. in diameter if the rod breaks under a load of 31,000 pounds?

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12. If the breaking stress of wrought iron is 47,000 lb. per square inch, what load will a rod 0.25 in. in diameter support when a safety factor of 4 is required?

13. A plate $\frac{9}{16}$ in. thick has a shearing stress of 60,000 lb. per square inch. What force is necessary to drive a punch $\frac{3}{8}$ in. in diameter through the plate?

14. If the tensile breaking stress of structural steel is 65,000 lb. per square inch, what is the diameter of a rod which breaks under a load of 130,000 pounds?

AREA THREE

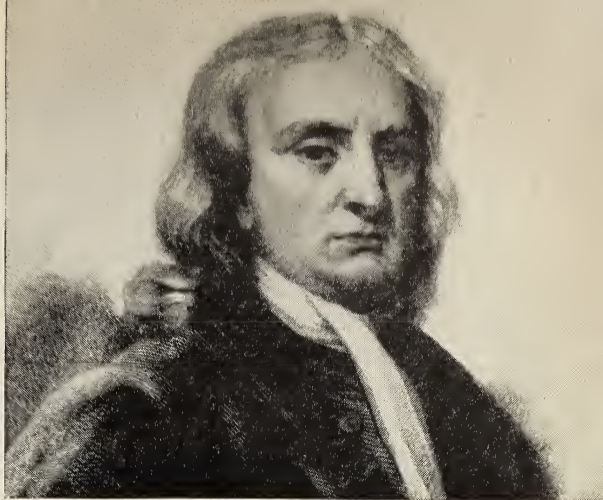
How Are Objects Affected by the Force of Gravity?

Earlier in the book we learned that all objects at or near the surface of the earth are acted upon by a force known as gravity. This force, which is measured in terms of weight, varies according to the mass, or the quantity of materials of which the objects are composed. Thus a large object weighs more than a small object of the same material, and an object of great density, or one in which the molecules are crowded closely together, weighs more than an object of the same size of low density. Now let us see how the force of gravity works in the world.

The law of gravitation. We are concerned not only with the force of gravity that is caused by the attraction of the earth for objects at or near its surface, but also with other forces of attraction acting among objects, known as the forces of gravitation. When an apple falls to the earth, for example, the earth attracts the apple and the apple attracts the earth. If the apple had as great mass as the earth, it would pull the earth halfway to meet it rather than fall all the way to the ground. In a similar manner all objects upon the earth attract one another, and even all objects in the universe, including the sun, moon, and stars. As a matter of fact, it is the force of gravitation that holds all the heavenly bodies together to form the universe.

Sir Isaac Newton
(1642-1727)

Sir Isaac Newton was an English scientist and mathematician, born about the time of Galileo's death. Like Galileo, he was interested in experimental science and continued Galileo's investigations, especially those applying to objects in motion. As a result, he formulated the law of gravitation and the three laws of motion. He also made many important findings in the field of mathematics.



Earlier we learned how Galileo studied gravitation by dropping weights from the leaning tower of Pisa. The first person to continue the study was an English scientist and mathematician by the name of Sir Isaac Newton. This famous scientist made many observations of the movements and relative positions of heavenly bodies and finally arrived at a law explaining the forces of attraction. This law, known as the law of gravitation, is commonly stated as follows: *Every particle of matter in the universe attracts every other particle with a force that is directly proportional to the product of their masses and inversely proportional to the squares of the distances between their centers of mass.*

Example. If a person weighs 160 pounds at the earth's surface, which is approximately 4000 miles from the center of the earth, how much would he weigh if he could travel to a height of 1000 miles above the surface?

Solution. To solve this problem, we apply the portion of the law that states that the force of attraction between objects is inversely proportional to the squares of the distances between their centers of mass. Accordingly we may express the computation in the form of a proportion as follows:

$$\begin{aligned}160 : W &= 5000^2 : 4000^2 \\25,000,000 W &= 2,560,000,000 \\W &= 102.4 \text{ pounds.}\end{aligned}$$

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On the basis of the law of gravitation we can readily see why objects weigh slightly more at the foot of a mountain than on the top of the mountain. We can see also why objects weigh more at the North or South Pole than at the equator. The difference in distance in each situation is sufficient to affect the force of gravitation acting between the centers of the objects and the center of the earth. Applying the law to objects within the earth, as in a deep mine, we might think that such objects weigh more than they would at the surface. As a matter of fact, however, objects beneath the surface weigh less than objects at the surface because they are attracted by the mass of the earth above which tends to offset the attraction of the mass below. If an object could be taken to the center of the earth, it would weigh nothing because it would be attracted equally from all directions.

The center of gravity and equilibrium. Every object has a point at which the mass of the object centers with reference to its weight. This point is known as the center of gravity. In the case of a sphere of uniform density the center of gravity is the center of

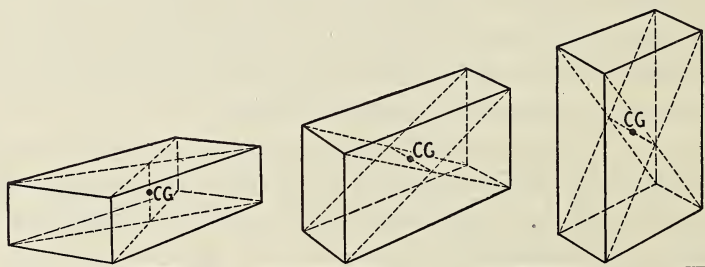


Fig. 61. Drawings indicating the center of gravity of a rectangular solid.

the sphere. In the case of a cube or rectangular object of uniform density, it is a point midway between the points of intersection of diagonal lines drawn upon opposite faces of the object, as shown in Figure 61. In the case of a flat object of irregular design, it is the point at which lines meet when the object is hung from different points along the edge and lines are drawn straight downward from the points of suspension.

THE FORCE OF GRAVITY

The center of gravity of an object determines in many instances whether the object is at rest or in motion. When an object is completely at rest, it is said to be in a state of equilibrium. When an object is in motion, it may move in one of two primary directions: first, it may follow a straight line, or have translatory motion; or second, it may rotate about a pivotal point, or have rotational motion. An object is in equilibrium with reference to translatory motion when the forces acting upon the opposite sides of the object are the same. Two workmen, for instance, may push on opposite ends of a hand truck in a factory. If they push with equal force, the truck remains motionless or in a state of equilibrium. If both men push on the same end of the truck, the truck takes on translatory motion, or moves in a straight line. If one man pushes at the head of the truck with a certain force and the other man pushes at the foot of the truck with less force, again the truck takes on translatory motion, moving toward the man exerting the smaller force.

An object is in a state of equilibrium with reference to rotational motion when the forces acting upon the opposite sides of a point are equal and acting at equal distances from the point. Thus a seesaw is in a state of equilibrium when the people using the seesaw are of equal weight and sit equal distances from the center of rotation. If they remain perfectly quiet, the seesaw will come to rest. On the other hand, if one person weighs more than the other or if he sits farther from the center of rotation than the other, the seesaw takes on rotational motion.

The fulcrum and moments of force. The point around which an object turns, or the axis of rotation, is known as the fulcrum. In the case of a seesaw the fulcrum is the point where the seesaw pivots as the opposite ends go up and down. If we let the drawing in Figure 62 represent a bar or lever of equal cross section throughout its length, the fulcrum is exactly in the center, as

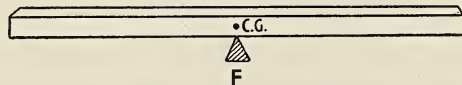
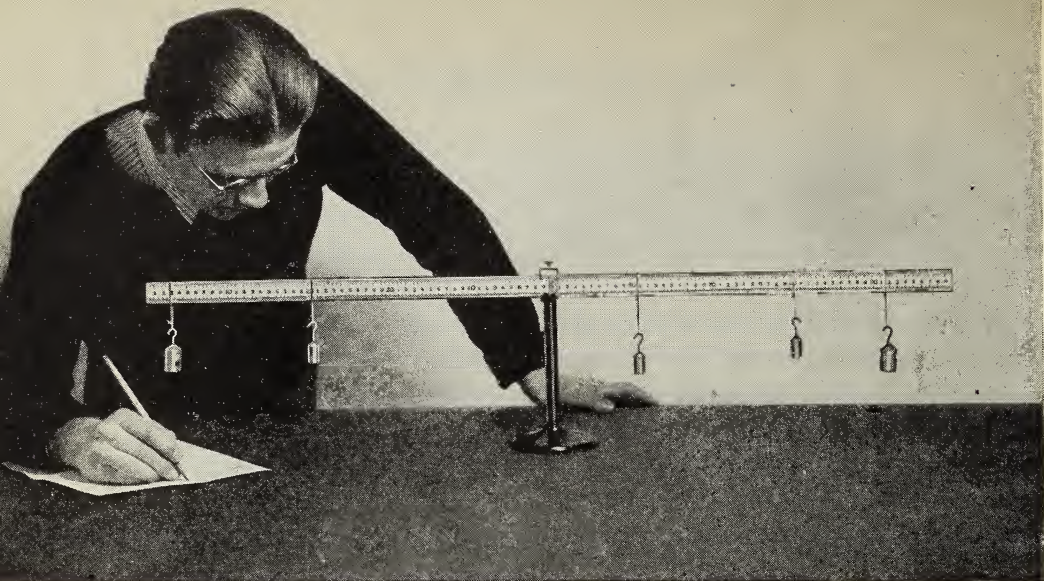


Fig. 62. The center of gravity of a uniform bar balanced on a fulcrum is directly over the fulcrum.



This student is performing an experiment to prove that, when a lever balances, the sum of the moments on one side of the fulcrum equals the sum of the moments on the other.

indicated by F . The bar balances at F because there is just as much weight upon one arm as upon the other. Immediately above F is the center of gravity of the bar, indicated by C.G., where the weight of the bar seems to be concentrated.

Now let us consider a similar bar with weights attached, as shown in Figure 63. The bar is of uniform cross section and balances at F directly below the center of gravity. Weights W_1 , W_2 , and W_3 are hung from the bar at such distances, d_1 , d_2 , and d_3 , that the bar continues to balance. Under this arrangement the weight of one arm of the bar offsets the weight of the other, and

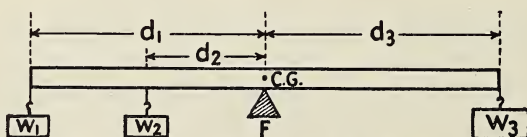


Fig. 63. This bar balances because the moments of force on the left of the fulcrum equal the moment on the right.

we need to consider only the suspended weights. The product obtained by multiplying one of the weights, as W_1 , by the perpendicular distance from

the weight to the fulcrum, as d_1 , is known as a moment of force. Since the bar is balanced, or in a state of equilibrium, the sum of the two moments of force to the left of the fulcrum equals

THE FORCE OF GRAVITY

exactly the one moment to the right. Accordingly, we may express the equilibrium in the form of an equation as follows:

$$W_1d_1 + W_2d_2 = W_3d_3.$$

Example. A seesaw of uniform cross section is supported so that it balances at the center of gravity. Three persons climb upon the seesaw, two on one end and one on the other end. One of the two persons weighs 120 pounds and sits 7 feet from the fulcrum. The other weighs 130 pounds and sits 5 feet from the fulcrum. If the person on the opposite end weighs 150 pounds, how far must he sit from the fulcrum to balance the other two?

Solution. To solve this problem, we substitute 120 for W_1 , 7 for d_1 , 130 for W_2 , 5 for d_2 , and 150 for W_3 in the above equation as follows:

$$120 \times 7 + 130 \times 5 = 150d_3.$$

Transposing and collecting, $150d_3 = 1490.$

Therefore $d_3 = 9.93 +$ feet.

If we consider further the balanced bar shown in Figure 63, we observe that the moment of force at the right of the fulcrum tends to make the bar turn clockwise and the two moments at the left tend to make the bar turn counterclockwise. Any moment that tends to make a bar turn counterclockwise is called a positive moment and is written with a positive sign, as $+W_1d_1$. A moment which tends to make a bar turn clockwise is called a negative moment and is written with a negative sign, as $-W_3d_3$. Since the bar under consideration is in a state of equilibrium, the two positive moments tending to make the bar turn counterclockwise equal exactly the one negative moment tending to make the bar turn clockwise. In other words, if we find the sum of the moments of force operating in the bar, the result is zero. We may express the computation as follows:

$$+(W_1d_1) + (W_2d_2) - (W_3d_3) = 0.$$

As we can readily see from the laws of algebra, we derive the above equation from the original equation by transposing the quantity W_3d_3 and letting the equation equal zero. The equa-

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tion shows that when a bar is balanced or in a state of equilibrium, the sum of the moments of force about the fulcrum is zero.

In preceding illustrations, since the levers were balanced at the center of gravity, we ignored the moments of force caused by lever arms. When levers are not balanced in this way, however, these moments must be considered. To understand this require-

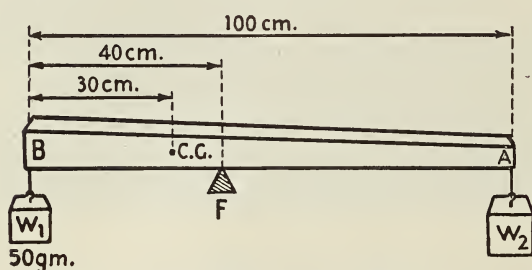


Fig. 64. Another bar that balances because the moments of force on the left exactly equal the moment on the right.

ment, let us consider the moments of force acting in the situation shown in Figure 64. In this instance the lever tapers from one end to the other; hence the center of gravity is to the left of the center as indicated by C.G.

Weights are hung on the ends of the lever as indicated by W_1 and W_2 , and the lever balances with the fulcrum at F . The moments of force then acting on the left side of the fulcrum, or the positive moments, are: first, the moment represented by the weight of the lever multiplied by the perpendicular distance from the center of gravity to the fulcrum; and second, the moment represented by weight, or force, W_1 multiplied by the perpendicular distance from the weight to the fulcrum. The moment of force acting on the right side of the fulcrum, or the negative moment, is represented by weight, or force, W_2 multiplied by the perpendicular distance from the weight to the fulcrum.

Example. Suppose the lever illustrated in Figure 64 is 100 centimeters long and weighs 140 grams. The center of gravity of the bar, as indicated by C.G., is 30 centimeters from end B, and a weight of 50 grams hangs from end B. What weight must be hung from end A to balance the lever if the fulcrum is placed 40 centimeters from end B?

Solution. To solve this problem on the basis of the foregoing explanation of moments, we let 140×10 represent the moment

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of force of the bar and 50×40 represent the moment of force caused by weight W_1 . Both these moments are positive because they tend to turn the bar counterclockwise. Opposed to these moments is the moment represented by $W_2 \times 60$ or $60W_2$, which is negative because it tends to turn the bar clockwise. Accordingly we may indicate the moments acting on the bar by writing an equation as follows:

$$-60W_2 + (50 \times 40) + (10 \times 140) = 0.$$

Transposing and dividing by -1 , $60W_2 = 2000 + 1400$.

Collecting,

$$60W_2 = 3400.$$

$$W_2 = 56\frac{2}{3} \text{ gram.}$$

Center of gravity and stability. The center of gravity has great bearing upon the stability of an object. If we accidentally tip a tumbler of water, for instance, to the extent that a vertical line drawn from the center of gravity of the contents falls outside the area of the bottom of the tumbler, the vessel upsets. On the other hand, if we tip a tumbler and a vertical line from the center of gravity of the contents falls within the area of the bottom of the tumbler, the vessel rights itself.

In general, the lower the center of gravity in an object, the more stable is the object. A canoe is more stable when the occupants are seated than when the occupants stand. A book is more

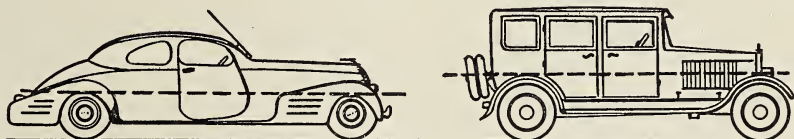


Fig. 65. The modern automobile on the left is safer than the older model on the right because it has a lower center of gravity, as indicated by the straight dotted lines.

stable when it lies flat on a table than when it stands on end. A fast-going vehicle, such as a streamline train or an automobile, is more stable when the vehicle is built low rather than high. Figure 65 shows why an automobile with a low center of gravity is safer than an automobile with a high center of gravity.

EXPLORING THE UNIVERSE OF FORCE

The stability of an airplane. One of the most interesting forms of stability is the stability of an airplane. By the stability of an airplane we mean its tendency to return to steady flight without the aid of the pilot after it has been disturbed by some such force as a gust of wind. Since the airplane is free to move forward, right or left, and up or down, it may be said to move in three dimensions. In order to accomplish these movements, it turns on three axes either separately or collectively as shown in

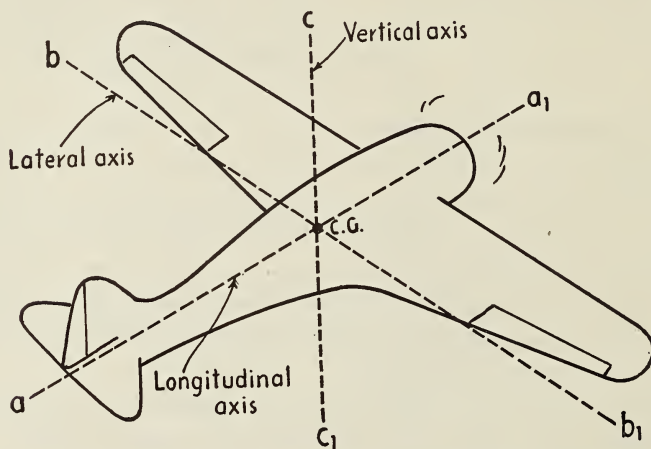


Fig. 66. The diagram above shows the three axes about which an airplane turns during an ordinary flight. At what point do the axes meet? What is this point called?

Figure 66. When the airplane rolls, or raises one wing higher than the other, it turns on its longitudinal axis indicated by aa_1 in the drawing. When it pitches, or climbs upward or drops downward, it turns on its lateral axis indicated by bb_1 in the drawing. When it yaws, or turns to the right or left, it rotates about its vertical axis indicated by cc_1 in the drawing. The three axes meet one another at the center of gravity of the airplane indicated by C.G. in the drawing.

Longitudinal stability. The forces that cause an airplane to recover automatically from a dip or climb and to resume flight in the original direction give the airplane longitudinal stability.

THE FORCE OF GRAVITY

These forces come into play when a gust of wind strikes the tail pieces and raises or lowers the rear of the airplane. Ordinarily the forces cause the airplane to dip or climb beyond its original path and then to oscillate slightly before it assumes the direction that it is supposed to follow. The factors that affect the longitudinal stability of an airplane are the center of gravity of the airplane, the center of pressure upon the airfoil, the tail plane, the down-wash, the thrust, and the drag.

The center of gravity, as in any other object, is the point where the mass of the airplane centers with reference to its weight. Also, since the three axes intersect one another at this point, it is the center of all the forces acting upon the airplane. The location of this center is exceedingly important, for the weight of the airplane must help to counteract the forces acting along the various axes. Thus designers in planning the parts of an airplane work hard to obtain a suitable center of gravity for the parts as a whole, and pilots watch to see that passengers and cargo disturb the center of gravity as little as possible.

One reason why people may ride in comfort in an airplane is the stability of the airplane, which comes from scientific designing. Engineers work extremely hard to achieve the right combination of parts for a delicate balance in all directions.

United Air Lines



EXPLORING THE UNIVERSE OF FORCE

The center of pressure upon the airfoil is the point where all the air forces affecting the surfaces seem to center. Each surface has a center of pressure of its own, which along with the other centers of pressure help to determine the center of pressure for the complete airfoil. The center of pressure upon a wing moves forward or backward, depending upon the angle of attack, or the angle that the chord of the wing forms with the streamlines. When the angle is large the center of pressure is close to the leading edge, and when the angle is small it is farther away from the leading edge. Under normal conditions the center of pressure produces the maximum lift when it is situated about one-fifth the distance of the width of the wing from the leading edge.

The tail plane of an airplane consists of a fixed horizontal plane, known as the stabilizer, extending crosswise, and smaller movable planes, known as the elevators, attached to the rear of the stabilizer. By adjusting the elevators the pilot causes the air to strike the surface of the stabilizer at a different angle from the angle at which the air strikes the surface of the wings.

The down-wash of an airplane is a downward motion of air from the wings to the top of the stabilizer, causing a downward pressure on the stabilizer. This downward motion varies with the speed of the airplane and helps to balance the airplane. Thus if the airplane loses speed, the down-wash exerts less force on the stabilizer, and the airplane points downward. The airplane then gains speed, the down-wash exerts greater force on the stabilizer, and the airplane returns to a horizontal position.

The thrust of an airplane is the force that causes the airplane to move forward in its course. This force comes from the propeller and may or may not center on the longitudinal line, which passes through the center of gravity.

The drag of an airplane is the force that tends to retard the speed of the airplane. This force, which is caused chiefly by air resistance, like the thrust may or may not center on the longitudinal line, which passes through the center of gravity.

Now let us consider the combined effects of the foregoing forces by noting their relative points of application, direction, and mag-

THE FORCE OF GRAVITY

nitude in Figure 67. The force of gravity, or weight of the airplane, centers at W , the force of lift on the wings because of air pressure centers at L , the force of lift on the tail plane because of air pressure centers at T , the force of thrust centers at Th , and the force of drag centers at D . The airplane is in longitudinal stability with uniform velocity and altitude when the following

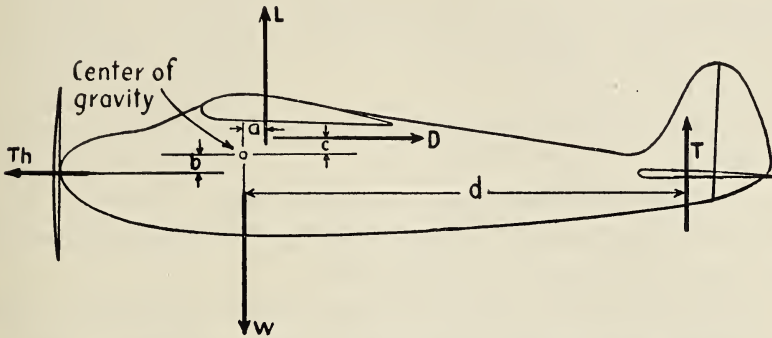


Fig. 67. Drawing of a modern airplane showing location of the center of gravity.

conditions obtain: first, the algebraic sum of the vertical forces L , W , and T equals zero; second, the algebraic sum of the forces Th and D equals zero; and third, the algebraic sum of the moments of force about the center of gravity equals zero. In the case of the drawing these moments of force are L times a , Th times b , D times c , and T times d . Since arm d of force T is relatively long, we can see why a change in the angle of the stabilizer has great effect upon the center of gravity.

Lateral stability. The forces that cause an airplane to right itself after a gust of wind has caused it to roll, or lift one wing higher than the other, gives the airplane lateral stability. Such stability comes partly from the position of one wing in relation to the position of the other and from the position of one side of the fin in relation to the position of the other. The wings of an airplane are set in the form of a broad **V** rather than extended on a longitudinal plane. The broad angle formed by the wings is a dihedral angle, which according to geometry is an angle formed by the intersection of two plane surfaces. For practical purposes,

EXPLORING THE UNIVERSE OF FORCE

however, engineers ignore the broad **V** formed by the wings and give special attention to the smaller angle, known as the dihedral angle, between the lower surface of each wing and the lateral axis,

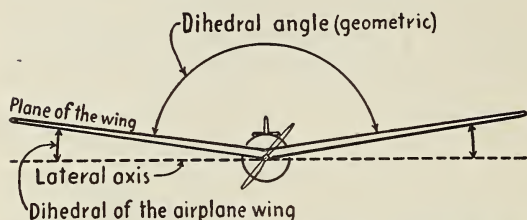


Fig. 68. A diagram showing the dihedral angle between the lower plane of the wing and the lateral axis.

axis, as shown in Figure 68. Constructing an airplane with such angles is said to be giving an airplane dihedral. When an airplane rolls or slips, the lower wing, because of its dihedral angle, is

more nearly horizontal than the upper wing. Thus the lift on the lower wing becomes greater than the lift on the upper wing and causes the airplane to right itself.

Directional stability. The forces that cause an airplane to regain its straight course after a gust of wind has caused it to yaw, or to turn to the right or the left, give the airplane directional stability. The stability comes from forces of air pressure acting upon the fin surfaces back of the center of gravity. These forces cause the airplane to right itself in much the same manner as a weather vane turns in the direction of the wind.

ANSWER THESE QUESTIONS

1. What is the law of gravitation? How does this law help to explain attraction between an apple and the earth?
2. Why do objects weigh more at the North and South poles than at the equator? Why do objects in a deep mine weigh less than objects at the surface?
3. What is meant by center of gravity? Where is the center of gravity in a sphere of uniform density? in a rectangular solid? in an irregular object of flat design?
4. When is an object in a state of equilibrium? In what two primary directions may an object move when it is in motion?
5. What is meant by a fulcrum? What is meant by a moment of force? How does an ordinary seesaw illustrate both a fulcrum and moments of force?

THE FORCE OF GRAVITY

6. How may the moments of force acting upon a balanced bar be represented in the form of an equation? Which moments may be considered positive and which negative?

7. How is the moment of force that is caused by the weight of a bar determined?

8. What relation exists between the center of gravity of an object and the stability of an object? Why are persons safer in a canoe when they sit down than when they stand up?

9. What is meant by the stability of an airplane? What separate movements has an airplane resulting in three sets of axes?

10. What forces acting upon an airplane help to give the airplane longitudinal stability? How does the center of pressure shift upon a wing surface? How does the down-wash help to produce stability?

11. What conditions must obtain for an airplane to maintain longitudinal stability with uniform velocity and altitude?

12. What forces help to give an airplane lateral stability? What is meant by giving an airplane dihedral?

13. What forces help to give an airplane directional stability? How does the fin cause the airplane to resemble a weather vane?

SOLVE THESE PROBLEMS

A

1. If the earth were one-half its present mass and the moon were double its mass, how would their force of attraction be affected?

2. If the distance between the sun's center of gravity and the earth's center of gravity were twice as great, how would their force of attraction be affected?

3. If a boy can jump 6 feet high on the earth, how high could he jump on the moon, where gravity is one-sixth as great as on the earth?

4. How much would a 200-lb. man weigh if he could go to the center of gravity of the earth?

B

5. A body weighs 1000 lb. at the earth's surface. If the diameter of the earth is 8000 mi., how much will the body weigh 5 mi. above the surface?

6. How high above the earth's surface would the body in problem 5 have to be in order to weigh only 500 pounds?

EXPLORING THE UNIVERSE OF FORCE

AREA FOUR

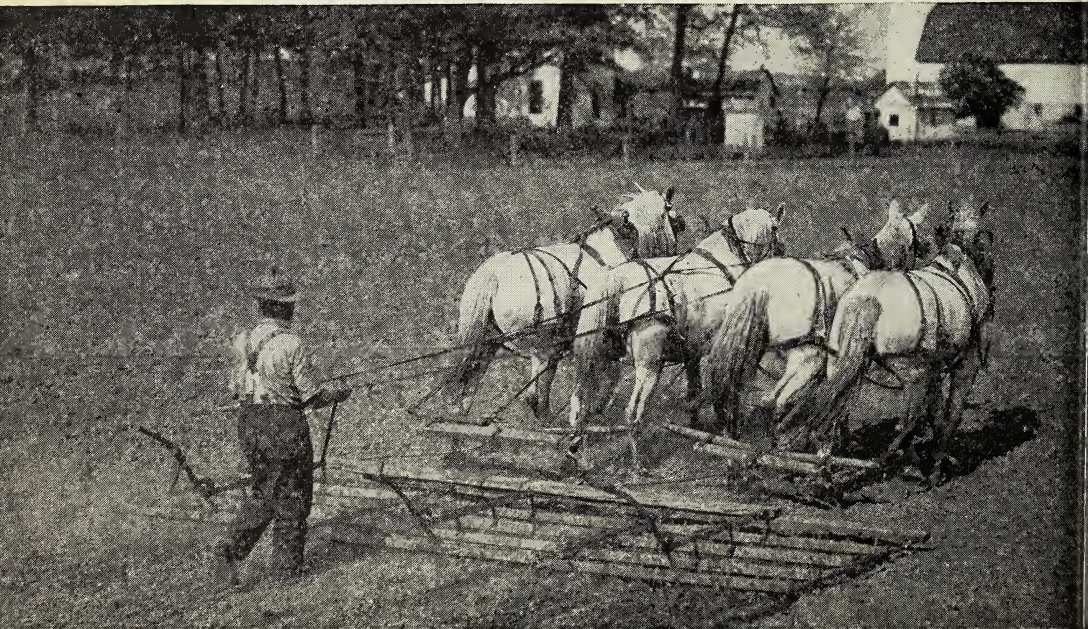
How Is the Magnitude of Two or More Forces Determined?

In the previous area we considered single forces acting in situations, as when a locomotive pulls a train. Frequently, however, we are concerned with more than one force acting in a situation, as when we row a boat in a stream. In this case we are concerned both with the force exerted by the oars and with the force exerted by the current. If we row downstream the forces act together, if we row upstream they oppose each other, and if we row across the stream they act at an angle with each other. To understand the result of such forces, we need to plot the forces geometrically and compute the combined value.

When are forces said to be parallel? Two or more forces are said to be parallel when they act in the same or in opposite directions. Two or more horses hitched side by side act as parallel forces when they pull a plow or a harrow. Two locomotives forming a double-header act as parallel forces when they pull a train of cars. In both these cases the forces move in the same direction, hence the resulting force equals the sum of the separate forces.

The farmer in the picture below is driving a team of four beautiful horses hitched to a harrow. The horses exert forces in parallel, for they pull in the same direction.

Century Photos, Inc.



THE MAGNITUDE OF TWO OR MORE FORCES

Two groups of boys act as parallel forces when they pull in opposite directions in a tug of war. Two men act as parallel forces when they push upon opposite sides of a box. In both these cases the forces move in opposite directions, hence the resulting force equals the difference between the separate forces. We may demonstrate the principle of parallel forces acting in opposite directions by suspending spring balances and weights from cross bars as shown in Figure 69.

The spring balances *A*, *B*, and *C* represent the forces acting in one direction, and the weights *W* and *W₁* represent the forces acting in the opposite direction. The sum of the readings on the spring balances equals exactly the sum of the weights plus the weight of the lower cross bar; therefore the difference between the opposite forces is zero.

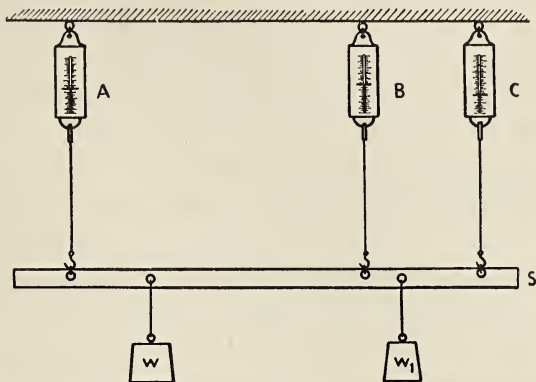


Fig. 69. This drawing shows apparatus for measuring parallel forces. What forces are acting in the drawing?

What is meant by composition of forces? Many forces act at angles to each other rather than in parallel lines. To determine the combined effect of two or more forces acting from a given point, we must convert the forces into a single imaginary force that could act in their stead. The conversion of separate forces into a single imaginary force is known as the composition of forces. In the process of conversion we use straight-line segments to represent the forces, for such segments enable us to indicate the magnitude and the direction of the forces. For example, if a force of 20 pounds moves from a point in a certain direction and another force of 10 pounds moves from the same point at right angles to the first, we may represent these forces by drawing two lines from a point, one perpendicular to the other. If we use a scale

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of one inch for 10 pounds in our drawing, as shown in Figure 70, we extend OA one inch from point O to represent the force of 10 pounds. We extend OB two inches from O at right angles to OA to represent the force of 20 pounds.

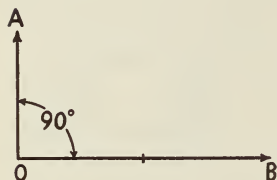


Fig. 70. Two forces acting at right angles to each other, as indicated by the arrows.

The next step after we have plotted forces as indicated above is to determine the imaginary force that might take their place. Suppose that we wish to determine the imaginary force that might take the places of two forces of 30 pounds and 40 pounds respectively, which move from a given point at right angles to each other.

First we draw two lines OA and OB as before at right angles to each other to represent the forces as shown in Figure 71. If we use a scale of one inch for 10 pounds, we make OA three inches long and OB four inches long. Next we complete a parallelogram by drawing BR parallel to OA and AR parallel to OB . As a final step we draw the diagonal OR , which we measure and find to be five inches long. According to our scale five inches represents 50 pounds. Thus we may assume that the two forces of 30 pounds and 40 pounds moving directly at right angles to each other produce the same result as a single force of 50 pounds moving in the direction of OR . A single force that represents the result of two or more forces is called the resultant of the forces. When only two forces are involved and these forces are represented by the adjoining sides of a parallelogram, the diagonal of the parallelogram

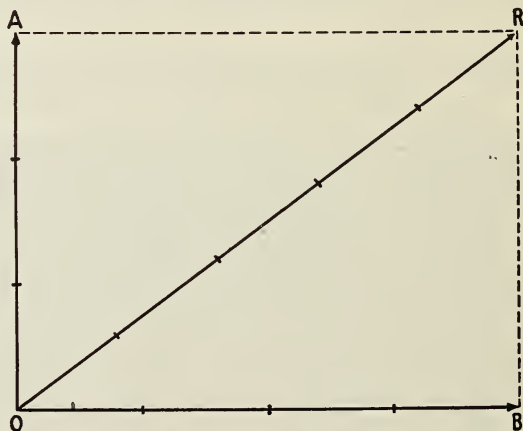


Fig. 71. Two forces acting at right angles to each other with their resultant, indicated by the diagonal. How is the resultant of two such right-angle forces determined?

THE MAGNITUDE OF TWO OR MORE FORCES

always represents the resultant. In plotting forces in this manner we must be very accurate, of course, because a slight error in the size of the angles or in the direction of lines changes the length of the diagonal.

Whenever two forces move at right angles to each other, as shown in Figure 71, the diagonal of the parallelogram becomes the hypotenuse of a right-angle triangle of which the two forces are the sides. According to a proposition of geometry, the square of the hypotenuse of a right triangle equals the sum of the squares of the other two sides. Therefore $OR^2 = OA^2 + OB^2$. If we substitute 30 pounds for OA in this equation and 40 pounds for OB , then the equation reads: $OR^2 = 30^2 + 40^2$ or $OR = 50$ pounds. If we substitute 3 inches for OA and 4 inches for OB in the equation on the basis of our scale, the equation reads: $OR^2 = 3^2 + 4^2$ or $OR = 5$ inches. Then, since one inch on the scale represents 10 pounds, 5 inches represents 50 pounds.

If the angle between two forces is more or less than a right angle, the resultant is equal to the length of the diagonal of the parallelogram multiplied by the scale per unit force used in representing the forces. For example, suppose that two forces of 50 and 80 grams act at an angle of 40° from each other as shown in Figure 72. If we draw OA and OC to represent the forces, using a scale of 1 centimeter for 25 grams, we make the first line 2 centimeters long and the second 3.2 centimeters long. Then we complete the parallelogram by drawing lines AB and CB and draw the diagonal OB to represent the resultant. Finally we measure OB , which we find to be 4.9 centimeters long and multiply this length by 25, the number of grams per centimeter according to our scale, and obtain 122.5 grams as the numerical value of the resultant.

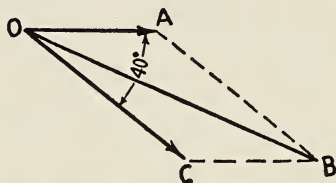


Fig. 72. The resultant of forces acting at more or less than a right angle.

When three forces act from a given point at different angles to one another, we find the resultant of two forces and then find the resultant of this resultant and the third force. If four or more

EXPLORING THE UNIVERSE OF FORCE

forces act from a point, we merely continue the method outlined for three forces until we have used the last force. Suppose, for

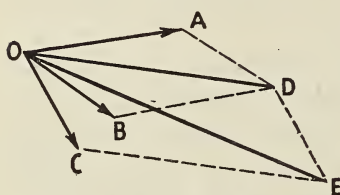


Fig. 73. The resultant of three forces is represented by a second diagonal.

instance, that three forces, indicated by lines OA , OB , and OC , move from point O as indicated by the arrows in Figure 73. To find the resultant of these forces, we first complete the parallelogram $OADB$ by drawing BD parallel to OA and AD parallel to OB and then draw the diagonal OD . Next we let OD represent a force acting

with OC and complete the parallelogram $ODEC$, by drawing CE parallel to OD and DE parallel to OC . Then we draw the diagonal OE , which represents the final resultant of the forces.

What is meant by an equilibrant? A force that prevents the motion of two or more forces acting at a given point is known as an equilibrant. Such a force, as we can see, is always equal and opposite to the resultant of the forces. Suppose two forces of 30 and 40 pounds respectively are acting at right angles to each other as indicated by lines OA and OB in Figure 74. The resultant of these forces is OR , which, interpreted quantitatively, is equal to 50 pounds. To represent the equilibrant, we draw OR_1 in the opposite direction from OR and make it the same length as OR .

To understand further the meaning of an equilibrant, suppose we consider a weight of 1000 grams suspended from cords attached to spring balances and

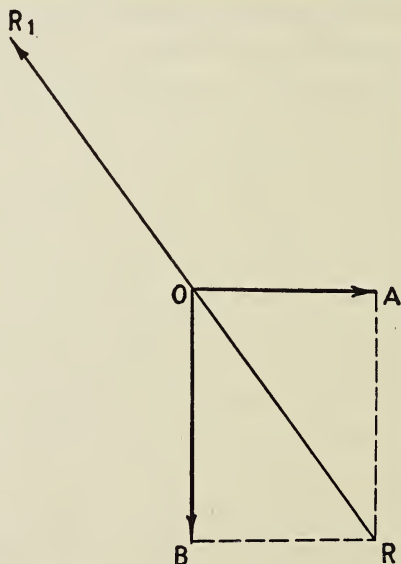
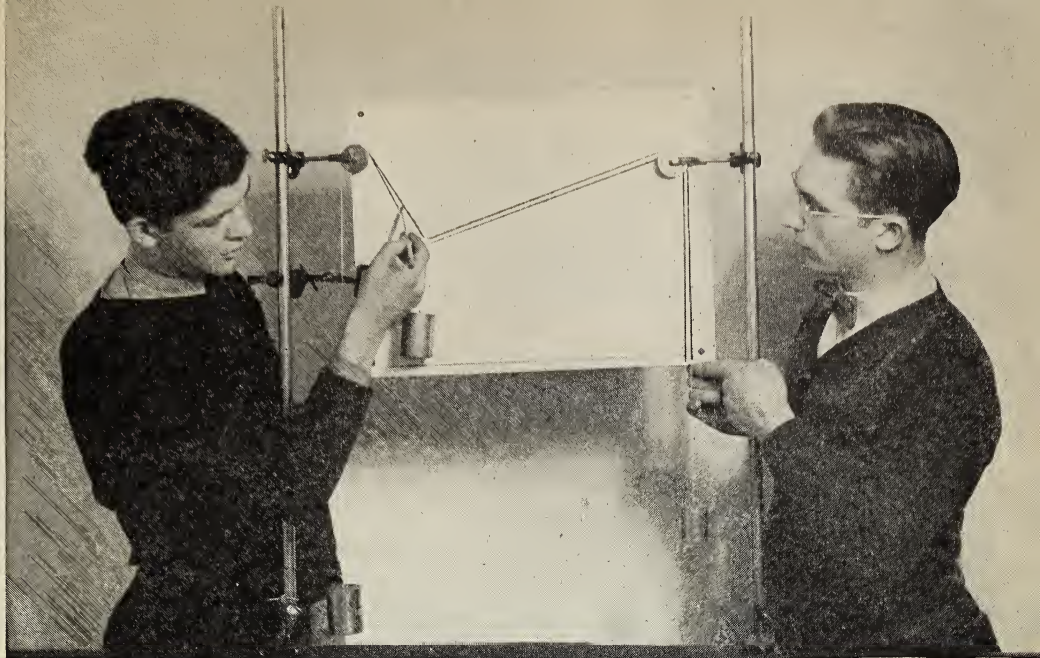


Fig. 74. The equilibrant is always equal and opposite to the resultant of the forces.



The boys in the above picture have performed an experiment with weights to determine the equilibrant of two forces and are now tracing their findings on paper.

placed at right angles to each other as shown at the left in Figure 75. The cords with spring balances attached, namely OA and OB , act as forces pulling in the direction indicated by the arrows, and OR represents the equilibrant of the forces pulling in the direction of R . To clarify the action of these forces, we may construct a parallelogram as shown at the right of Figure 75, making

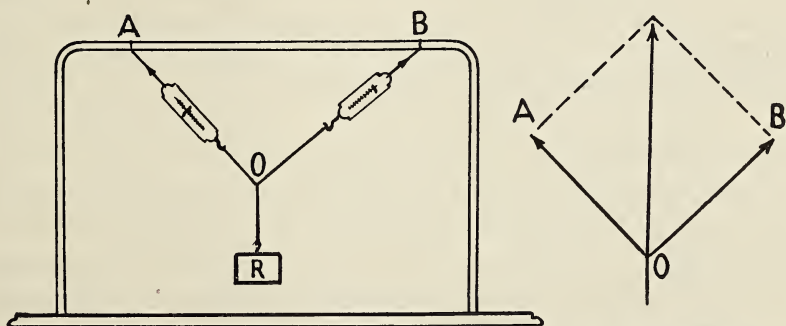


Fig. 75. The drawing at the left shows apparatus for measuring the equilibrant of two forces. The drawing at the right is a diagram of the two forces and resultant.

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the length of OA correspond to the reading on the left-hand balance and the length of OB correspond to the reading on the right-hand balance. Then if we compute the resultant of the forces we find that it equals 1000 grams and is therefore numerically the same as the force exerted by the weight suspended from point O .

Analyzing a single force. Besides being concerned with the conversion of separate forces into a single force, we are also concerned with breaking a single force into separate forces. For example, if a boy pulls a sled in a horizontal direction with a force of 100 pounds and holds the rope at an angle of 30° to the horizontal, how much of the force tends to lift the sled? In such a situation the force of 100 pounds may be considered a resultant of two forces acting at right angles to each other, one tending to move the sled forward horizontally and the other to lift the sled perpendicularly. Therefore we construct a parallelogram as

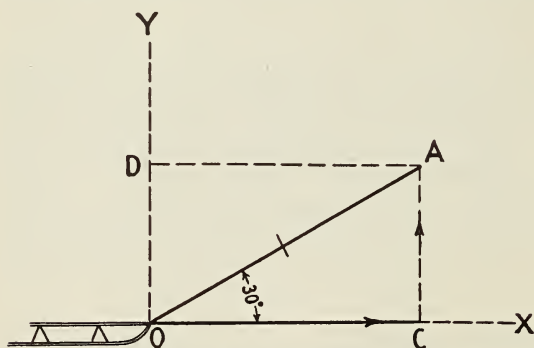


Fig. 76. A single force may often be converted into two component forces acting at right angles to each other.

shown in Figure 76, with diagonal OA to represent the resultant force of 100 pounds and sides OD and OC to represent the separate forces. If we use a scale of one inch for 50 pounds, we make OA exactly 2 inches long. Then we draw OX at a 30° angle to OA and drop a line

from A perpendicular to OX that cuts OX at C . The line OC represents the force tending to pull the sled forward horizontally. Next we draw OY perpendicular to OX and extend a line from A perpendicular to OY that cuts OY at D . The line OD represents the force tending to lift the sled perpendicularly. As a final step we measure OC and OD and apply the scale of one inch for 50 pounds, on the basis of which the parallelogram was constructed.

THE MAGNITUDE OF TWO OR MORE FORCES

Any force similar to OC or OD that represents part of a single force is known as a component of the force. The component of a force in a given direction is the effective part of the force that acts in the direction. Thus OC is an effective component of the force in a horizontal direction, and OD is an effective component in a vertical direction.

How gravity affects an automobile on a hill. Another illustration of a single force that may be broken into component parts is the force of gravity as it affects an automobile climbing a hill. Suppose an automobile that weighs 3000 pounds is climbing a hill, as shown in Figure 77, and we wish to know how much of the force of gravity is holding the automobile back and how much is causing it to exert pressure upon the hill. First we draw the vertical line RS to represent the resultant and hence to serve as the diagonal of a parallelogram. Next we draw RX parallel to the slope of the hill and extend a line from S perpendicular to RX that cuts RX at W . Finally we complete the parallelogram by drawing a line from R parallel with WS and a line from S parallel with WR , which lines meet at N . In the completed parallelogram the side RW represents the component that holds the automobile back and the side WS represents the component that causes it to exert pressure upon the hill.

Now we draw triangle AOB to show the length and height of the hill that the automobile is climbing. This triangle is similar to triangle SWR because both are right triangles and acute angle SRW of triangle SWR equals acute angle ABO of triangle AOB . Therefore, according to a proposition of geometry, the corresponding sides of the triangles are proportional, and $\frac{WR}{OB} = \frac{SR}{AB}$

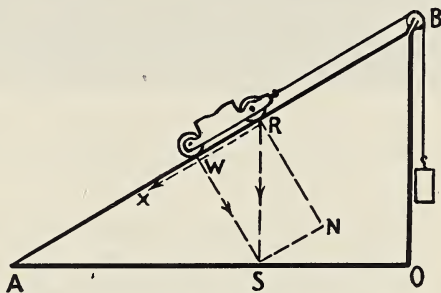


Fig. 77. A diagram showing the component of gravity that holds back an automobile on a hill.



Ferdinand Hirsh

A component of force that represents part of the force of the wind causes the sailboat to sail into the wind and thus seemingly overcomes one of the forces of nature.

or $\frac{WR}{SR} = \frac{OB}{AB}$. Thus we find that the force that holds the automobile back bears the same ratio to the weight of the automobile as the height of the hill bears to its length.

Example. An automobile that weighs 3000 pounds is traveling down a hill one-half mile long and 100 feet high. What part of the force of gravity tends to make the automobile run downhill?

Solution. To solve this problem, we let f represent the force to be determined and, on the basis of the last statement above, write the following equation:

$$\frac{f}{3000} = \frac{100}{2640} \text{ (feet in one-half mile).}$$

Clearing of fractions,

$$2640 f = 300,000.$$

$$f = 113.63 \text{ pounds.}$$

How a sailboat moves against the wind. A sailboat moves against the wind because one of the component forces of the wind that strikes the sail is effective in the direction in which the boat moves.

THE MAGNITUDE OF TWO OR MORE FORCES

If we look at Figure 78, we may see how the effective force acts. KK_1 in the drawing represents the line of the keel, SS_1 the surface of the sail, and R the rudder. When the wind blows in the direction indicated by the arrows and strikes the slanting sail, we may assume that the combined force of the wind centers at O and

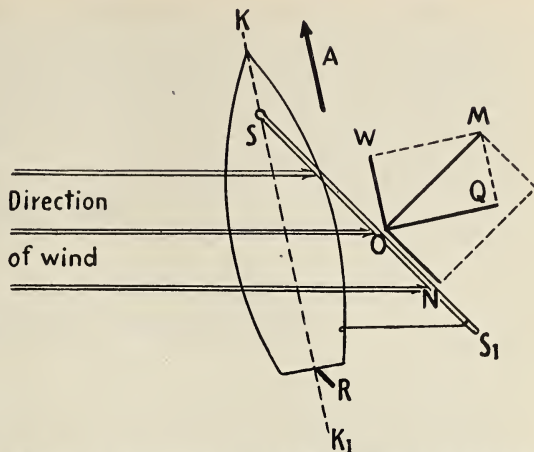


Fig. 78. A diagram showing the component of force that enables a sailboat to travel into, or against, the wind.

breaks into two components, OM , which is perpendicular to SS_1 and ON , which is parallel to SS_1 . The force OM breaks into two component parts, OQ , which is perpendicular to the keel, and OW , which is parallel to the keel. The force OQ tends to move the boat sidewise, but its effect is largely offset by the resistance of the water against the keel and the rudder. The force OW , on the other hand, tends to move the boat forward in the direction of arrow A . The force ON , one of the original components, has no effect upon the motion of the boat because it is parallel to the surface of the sail.

ANSWER THESE QUESTIONS

1. When are forces said to be parallel? How may the resulting forces be determined when parallel forces act in the same direction? How may the resulting forces be determined when the forces act in the opposite direction?
2. What is meant by the resultant of forces? How may the resultant of two forces that act at right angles to each other be determined? How may the resultant of two forces be determined when the forces act at an angle greater than a right angle or less than a right angle?
3. How may the resultant of three or more forces be determined?

EXPLORING THE UNIVERSE OF FORCE

4. What is meant by an equilibrant? How does the equilibrant compare in direction and magnitude with a resultant?
5. How may a single force be broken into component parts? When is it said to be effective in a given direction?
6. How may the force of gravity that acts upon an automobile going uphill be determined?
7. Why can a sailboat travel against the wind? Which component force causes the boat to move in such direction?

SOLVE THESE PROBLEMS

A

1. Three boys pull on the end of a rope in an easterly direction with forces of 100, 150, and 200 lb., respectively, and three other boys pull on the other end of the rope in a westerly direction with forces of 125, 160, and 175 lb., respectively. What is the resultant force and what is the direction of the resultant?
2. What is the resultant of two forces one of which is 30 lb. acting north and the other 40 lb. acting east? What is the direction of the resultant?
3. If two forces of 300 g. each move at an angle of 120° to each other, what is the resultant?
4. A wire 50 ft. long is stretched horizontally between two posts and a 400-lb. weight is hung from the wire midway between the posts. If the weight causes the wire to sag 2 ft. at the center, what is the tension on the wire?
5. How great a force is required and in what direction must the force act to counterbalance two forces of 60 lb. each, one acting east and the other north?
6. A person weighing 130 lb. sits in a swing the ropes of which are spread 45° from the vertical at the points of suspension. What is the tension on each rope of the swing?
7. What force because of gravity, with friction disregarded, causes a 5-ton truck to coast down a hill inclined 30° with the horizontal?
8. A boy pulls a sled with a force of 20 pounds. What component force causes the sled to move horizontally if the rope forms an angle of 60° with the horizontal?
9. A tugboat pulls with a force of 5 tons upon a cable attached to an ocean liner. If the cable forms an angle of 30° with the horizontal, what component force causes the liner to move forward?

CALCULATING ACCELERATED MOTION

B

10. Two forces acting at right angles to each other have a resultant of 100 pounds. If the larger force is 80 lb., how much is the smaller?

11. A boy pushes a lawn mower over a level lawn with a force of 60 pounds. If the handle of the mower forms a 30° angle with the lawn, what force pushes the mower forward? What force tends to push the mower into the ground?

12. Two boys weighing 120 and 130 lb. respectively stand facing each other at the center of the board in a rope swing. What is the tension on the ropes when the swing is at rest?

13. What is the tension on the ropes of the swing in problem 12 when the freely moving swing makes a 30° angle with the vertical?

14. A tractor pulls a plow over a level field with a force of 300 pounds. What force tends to make the plow move horizontally if the hitch forms an angle of 30° with the ground? What force tends to lift the plow?

15. One end of a plank is placed upon a box, causing the plank to form a 30° angle with the horizontal. With friction neglected, what force parallel to the plank is necessary to keep a barrel weighing 300 lb. from rolling toward the bottom?

16. A boy weighing 140 lb. rests in a rope swing. What tension is produced upon each rope of the swing if another boy pulls both the boy and the swing to one side until the ropes make an angle of 30° with the vertical?

17. A force of 2000 pounds is acting due east. How may this force be resolved into two components, one twice the magnitude of the other, acting at right angles with each other?

AREA FIVE

How May Accelerated Motion Be Calculated?

Frequently in everyday life we are concerned with steadily increasing motion as when we coast down a hill on a sled. The speed increases as we continue on our way and, if the hill is steep, may become so great that we lose control of the sled. Steadily increasing motion, such as the increasing speed of a sled, is known in the field of physics as accelerated motion.

EXPLORING THE UNIVERSE OF FORCE

The force of gravity a cause of accelerated motion. One of the greatest causes of accelerated motion is the force of gravity, or the pull toward the center of the earth. The first person to ex-

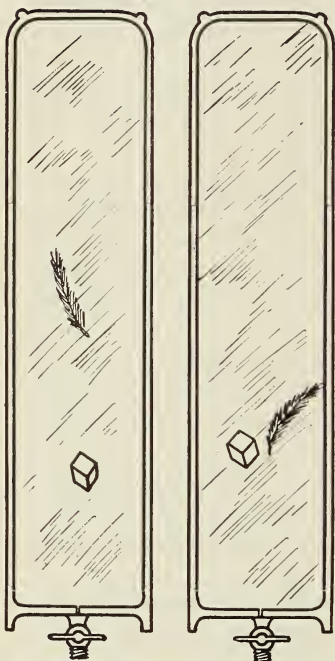


Fig. 79. An illustration showing how objects fall in air and in a vacuum.

periment with the force of gravity was the noted Galileo, who dropped objects of different sizes and densities from the leaning tower of Pisa. He concluded that if it were not for retardation caused by the resistance of air all objects would fall at the same rate of speed. Years later, after the vacuum pump was invented, other scientists experimented with gravity by dropping objects of various sizes and densities first in air and then in a vacuum. When they dropped two objects such as a small chunk of iron and a feather in a vessel filled with air, they found that the iron fell much faster than the feather, as shown at the left in Figure 79. When they dropped the iron and feather in a vessel from which the air had been removed—in other words, through a vacuum—

they found that the objects fell side by side or at the same rate of speed, as shown at the right in Figure 79. Thus they proved without question that Galileo's early conclusion was right, even though he lacked the means of experimenting accurately.

Since the days of Galileo scientists have carefully calculated acceleration caused by gravity and have found that falling objects have an acceleration of about 32.16 feet, or 980 centimeters, per second for each second that they fall. Thus at the end of one second an object moves with a velocity of 32.16 feet per second, at the end of the second second with a velocity of 64.32 feet per second, and at the end of the third second with a velocity of 96.48

CALCULATING ACCELERATED MOTION

feet per second. Since the force of gravity varies slightly at different locations on the earth, the acceleration caused by gravity also varies, as shown by the following table:

Boston, Mass.....	980.38 cm. per sec. per sec.
Chicago, Ill.....	980.26 cm. per sec. per sec.
Cleveland, Ohio.....	980.23 cm. per sec. per sec.
St. Louis, Mo.....	980.00 cm. per sec. per sec.
Pikes Peak, Colo.....	978.94 cm. per sec. per sec.

Besides giving accelerated motion to freely falling bodies, the force of gravity also gives accelerated motion to objects moving down an inclined plane, such as an automobile traveling downhill. In this case the force of gravity acts in two directions, or breaks up into two component forces. One component pulls the automobile downhill and the other causes it to exert pressure upon the hill. The steeper the hill, of course, the greater becomes the first component relative to the second and hence the greater becomes the accelerated speed of the automobile.

This winter scene shows a steep toboggan slide in Quebec, Canada. The thrill of riding on this slide depends upon acceleration in the speed of the toboggan produced by a component of gravity. The component acts parallel with the slide.

Canadian Government Motion Picture Bureau



EXPLORING THE UNIVERSE OF FORCE

Method of computing accelerated motion. When we say that gravity gives falling objects an accelerated motion of 32.16 feet per second, we mean that it causes the objects to gain 32.16 feet in velocity per second. This acceleration, or gain in velocity, continues through every second the object falls. If we wish to find the velocity at the end of any given time, we multiply 32.16 by the number of seconds the object has fallen. If an object has fallen four seconds, for example, we multiply 32.16 by four and obtain a velocity of 128.64 feet per second. To find the average velocity of a falling object starting from rest, we add the initial velocity, which is 0, to the final velocity, which is 128.64 feet per second, and divide the sum by two. In the case of an object that has fallen

four seconds, the computation is as follows: $\frac{0 + 128.64}{2} = 64.32$

feet per second. If we wish to find the total distance to the point to which an object has fallen, we multiply the average velocity of the falling object by the number of seconds it has fallen, as $64.32 \times 4 = 257.28$ feet.

Now suppose that we apply the foregoing information to falling bodies in general and arrive at equations that we may use in calculating the velocity at any given time, the average velocity, and the linear space, or distance, through which objects fall. The velocity of a falling body, starting from rest, at any given time equals the acceleration times the time during which the body has fallen, or $V = at$. The average velocity of a falling body starting from rest equals the beginning velocity, which is zero, plus the acceleration times the time, divided by two, or average $V = \frac{0 + at}{2}$,

or average $V = \frac{at}{2}$. The linear space, or distance, through which a body falls equals the average velocity multiplied by the time, or $S = \frac{at}{2} \times t$, or $S = \frac{at^2}{2}$. This equation holds true for all forms of acceleration, but for acceleration caused by gravity scientists commonly use the letter g for acceleration rather than a . Con-

CALCULATING ACCELERATED MOTION

sequently the equation for the linear space through which a body falls is commonly written as follows: $S = \frac{gt^2}{2}$.

Example. How far will an object dropped from an airplane fall in 10 seconds?

Solution. To solve this problem, we substitute 32.16 feet for g and 10 seconds for t in the foregoing equation, as follows:

$$S = \frac{32.16 \times 10^2}{2}.$$

Clearing of fractions, $S = \frac{3216}{2}.$

Therefore $S = 1608$ feet.

Often we need to find the relation between the velocity of a body, uniformly accelerated, and the distance through which the body travels. Already we have learned that velocity = acceleration $\times$ time, or $V = at$. Solving for t , we obtain $t = \frac{V}{a}$. Substituting $\frac{V}{a}$ for t in the equation $S = \frac{at^2}{2}$, we obtain $S = \frac{a}{2} \times \frac{V^2}{a^2}$, or $S = \frac{V^2}{2a}$.

Solving for V , we obtain the equation:

$$V = \sqrt{2aS}.$$

Example. If an object falls 1500 feet, what is its velocity in feet per second when it strikes the ground?

Solution. To solve this problem, we substitute 32.16 feet per second for a (since a and g in this instance are interchangeable) and 1500 feet for S in the foregoing equation as follows:

$$V = \sqrt{2 \times 32.16 \times 1500}.$$

Therefore $V = 310.61$ feet per second.

Computing accelerated motion of bodies already in motion. In the foregoing discussion we have considered only the accelerated motion of bodies starting from rest. Let us now consider the accelerated motion of bodies that are already in motion when the

EXPLORING THE UNIVERSE OF FORCE

acceleration begins. Suppose, for instance, that an automobile is traveling at a rate of 10 miles an hour when it starts down a hill; that the velocity is accelerated one-half foot per second per second by the force of gravity; and that we wish to know the speedometer reading at the end of three minutes. The part of the reading caused by the initial velocity of the automobile is 10 miles per hour. The part caused by the acceleration of gravity may be obtained by means of the equation $V = gt$. Thus we substitute given quantities in this equation as follows: $V = 0.5 \times 180$ (3 minutes changed to seconds), or $V = 90$ feet per second, or 61.3 miles per hour. Then we add 10 miles per hour, the part of the reading caused by the initial velocity, and 61.3 miles per hour, the part caused by the acceleration of gravity, and obtain 71.3 miles per hour, the total reading at the end of three minutes.

Now suppose that we wish to find the distance through which the automobile travels in three minutes. First we find the distance through which it travels because of its initial velocity of

This picture shows an automobile traveling along a mountain highway. When an automobile coasts downhill on such a highway its velocity increases in proportion to the acceleration caused by gravity and the length of time through which it travels.



CALCULATING ACCELERATED MOTION

10 miles per hour. We compute this distance as follows: 10×0.05 (3 minutes changed to hours) = 0.5 mile. Next we find how far the automobile travels because of accelerated motion. We compute this distance by substituting given quantities in the equation $S = \frac{gt^2}{2}$ as follows: $S = \frac{0.5 \times 180^2}{2}$ (3 minutes changed to seconds),

or $S = 1.53$ miles. Then we add 0.5 mile, the distance through which the automobile travels because of the initial velocity, and 1.53 miles, the distance through which it travels because of acceleration, and obtain 2.03 miles, the total distance traveled.

Now let us derive equations from the foregoing illustration to use in calculating: first, the velocity that a body possesses at the end of any given time as a result of accelerated motion; and, second, the distance through which it travels in a given time as a result of initial velocity and accelerated motion. The velocity that the body possesses at the end of any given time equals the initial velocity plus the velocity caused by acceleration, or $V = V_0$ (initial velocity) $+ at$. The distance through which the body travels in any given time equals the distance traveled because of the initial velocity plus the distance traveled because of accelerated velocity, or $S = V_0$ (initial velocity) $t + \frac{at^2}{2}$.

What goes up must come down. Whenever we throw a ball vertically into the air, the velocity of the ball decreases because of the pull of gravity until the ball reaches a certain height at which the velocity becomes zero. Then the ball reverses its direction of travel and starts back toward the earth. A similar condition prevails whenever any object is thrown or ejected vertically into the air. If we study the decrease in velocity, we find that it is 32.16 feet per second for each second during which the object rises. In short, we may think of the increase in velocity of falling bodies as positive acceleration and of the decrease in velocity of rising bodies as negative acceleration, for one is the direct opposite of the other. The equation for calculating the distance through which an object travels when affected by negative acceleration

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is the same as the equation used for calculating the distance through which an object falls when it has an initial velocity, except that $\frac{gt^2}{2}$ is considered negative rather than positive. Thus the equation for determining distance in the case of negative acceleration is $S = V_0 t - \frac{gt^2}{2}$.

Example. If a bullet is fired from a gun vertically with an initial velocity of 1200 feet per second, how high will the bullet travel in 5 seconds?

Solution. To solve this problem, we substitute in the foregoing equation as follows:

$$S = 1200 \times 5 - \frac{32.16 \times 5^2}{2}.$$

Collecting and clearing
of fractions,

$$S = 6000 - 402.$$

$$S = 5598 \text{ feet.}$$

How the parachute overcomes acceleration. In the foregoing discussion of acceleration caused by gravity the resistance of air was neglected, but this resistance always tends to retard falling bodies. An interesting device that tends to overcome acceleration caused by gravity is the parachute. This device consists of a canopy made of high-grade silk or pongee fabric, which opens in much the same manner as an umbrella and thus provides an expansive surface to meet the resistance of the air.

The parachute is widely used in jumping from airplanes, especially in times of war. To open the parachute, the user pulls a cord, known as the rip cord, when he is free from the airplane. Usually he pulls the cord about five seconds after he jumps, during which time his body acquires a velocity of 32 times 5, or 160 feet per second. A large vent in the apex of the parachute helps to overcome the stresses caused when the parachute first opens and begins to retard the downward velocity of the jumper. When the velocity has once been retarded by the resistance of air, the vent is partially closed by means of an elastic cord.

CALCULATING ACCELERATED MOTION

ANSWER THESE QUESTIONS

1. What is meant by accelerated motion? How great in feet per second per second is the acceleration caused by the force of gravity?
2. How does the force of gravity affect the speed of an automobile traveling down a hill? What two components of force are involved?
3. What equation may be used in calculating the average velocity acquired by an object because of the force of gravity? What equation indicates the distance an object falls when starting from rest?
4. What method is used in calculating the velocity of an object already in motion when it is affected by gravity? What method is used in calculating the distance through which the object moves?
5. What method is used in calculating the distance through which an object moves when it is affected by negative acceleration?
6. What is a parachute? How does the parachute tend to overcome acceleration caused by gravity?

SOLVE THESE PROBLEMS

A

1. An automobile travels at a uniform speed of 60 mi. per hour. How many feet does it travel in one second?
2. An airplane flies at a uniform rate of 200 mi. per hour. How many feet does it travel in one minute?
3. How fast does a freely falling body, starting from rest, move at the end of one second? What is the average velocity of the body?
4. How far does a freely falling body, starting from rest, move in one second? in three seconds? in five seconds?
5. How long does it take a brick to drop from the top of a tall building 800 feet high? How fast is the brick traveling when it strikes the ground?
6. How high does a bullet travel when it is fired vertically with an initial velocity of 1000 ft. per second?
7. How long does it take a bullet fired vertically with an initial velocity of 1100 ft. per second to reach its highest point? With what velocity does it strike the ground?
8. How high does a shell travel when it is fired vertically and strikes the ground again in 10 seconds? What is its initial velocity?
9. A batter hits a pitched ball which travels through the air for an interval of 5 seconds. How high does the ball rise and what is its initial velocity?

EXPLORING THE UNIVERSE OF FORCE

B

10. An automobile traveling at the rate of 50 mi. an hour is brought to rest in 10 seconds through the use of the emergency brakes. What is the negative acceleration in feet per second each second?

11. How many feet does the car travel in problem 10 after the brakes are applied?

12. A man driving an automobile at the rate of 60 mi. an hour sees danger ahead and applies the brakes. How far does the car continue after the driver sights danger if his reaction time is $\frac{3}{4}$ second and the brakes produce a negative acceleration of 12 ft. per second per second?

13. A hockey puck moves at a velocity of 60 ft. per second. If the friction of the ice retards the puck 3 ft. per second per second, how far will it go before it stops?

14. The velocity of a pair of rollers in a paper mill is increased in 40 seconds from 60 revolutions per minute to 150 revolutions per minute. What length of paper passes between the rollers in the 40 seconds if the rollers are 30 inches in diameter and there is no slippage?

15. A sand bag is dropped at a height of one mile from a balloon rising at the rate of 40 ft. per second. How long does it take the bag to reach the ground? With what velocity does the bag reach the ground?

AREA SIX

What Is the Significance of Newton's Laws of Motion?

Whenever we consider objects in motion, we find that they follow certain patterns of behavior. The first person to study motion critically was the English scientist Sir Isaac Newton, who expressed his conclusion in the form of laws commonly known as the laws of motion. Let us now see what these laws are.

The first law of motion. The first law of motion is stated as follows: *A body persists in a state of rest or uniform motion in a straight line unless acted upon by an outside force.* This law concerns the inertia of an object, or the property that tends to keep

NEWTON'S LAWS OF MOTION

an object at rest when at rest or in motion when in motion. Any force that causes a body at rest to move or changes the speed of a body in motion or the direction of the motion overcomes the inertia of the object. When a person beats a rug, for example, he drives the rug away from the particles of dust, because the inertia of the particles tends to cause them to remain at rest. Another example may be drawn from the method of tightening the handle of an ax or hatchet. If a person hits the end of the handle with a hammer, the handle moves farther into the axhead because the force of inertia tends to cause the ax to remain at rest. As evidence that an object in motion tends to continue in motion in a straight line unless acted upon by an outside force, we may recall the experience of having been thrown forward in an automobile when the brakes were suddenly applied.

The second law of motion. The second law of motion is stated as follows: *The acceleration of any body is directly proportional to and in the direction of the force acting upon it.* We may illustrate this law by drawing upon our experience with falling bodies. The force of gravity, as we have learned, gives freely falling bodies an acceleration of 32.16 feet per second per second. The accelerated motion always takes place vertically, or in the direction of gravity, which in this case is the acting force. Another illustration of accelerated motion is the motion acquired by an automobile as it travels downhill. In this instance the force that acts upon the automobile is a component of the force of gravity rather than the full force of gravity. This component acts parallel to the slope of the hill much as if it were a separate force pulling the automobile directly down the hill.

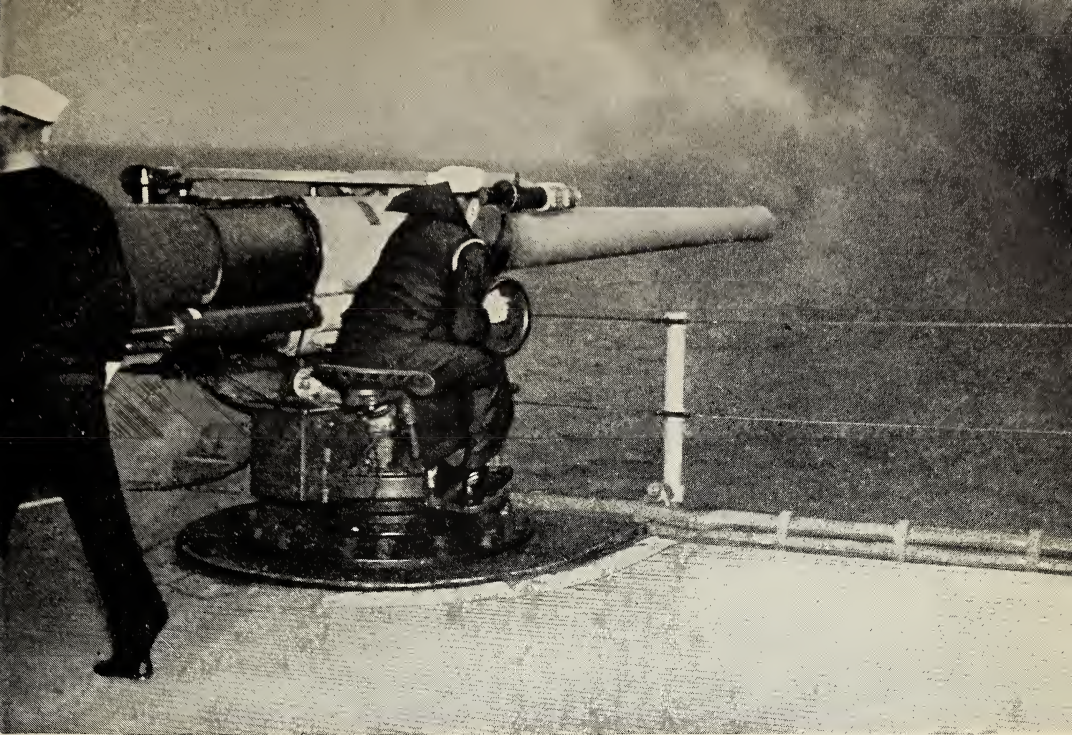
The third law of motion. The third law of motion is stated as follows: *For every action upon an object there is an equal and opposite reaction.* Whenever we stand on a ladder, the ladder pushes up with a force equal to our weight. Otherwise we should fall. When we lean against the wall of a building, we may assume that the wall pushes back with equal force. Otherwise the wall

EXPLORING THE UNIVERSE OF FORCE

would move. Another illustration of equal force comes from the fact that when we jump from a canoe or other small boat we shove the canoe backward. The force that we exert on the canoe, part of which makes the canoe move, is equal and opposite to the force that carries us ashore.

Units of force. In order to consider Newton's laws of motion we must use certain units of force. The scientist commonly divides the units of force into two classes, namely, gravitational units and absolute units. Gravitational units, as their name indicates, are units used in measuring the force of gravity, such units varying slightly at different places upon the earth's surface. Absolute units are units used in measuring forces independent of gravity, such units never changing in value. The gravitational units that are most commonly used are the pound and the gram. A pound force is the force required to cause a pound of mass to accelerate approximately 32.16 feet per second per second. A gram force is the force required to cause a gram of mass to accelerate approximately 980 centimeters per second per second. The absolute units that are most commonly used are the poundal and the dyne. The poundal is the force required to cause a pound of mass to accelerate one foot per second per second. The dyne is the force required to cause a gram of mass to accelerate one centimeter per second per second. From these definitions we can see that a pound force is approximately 32.16 times larger than a poundal, and a gram force 980 times larger than a dyne.

What is meant by momentum? If two football players of equal skill run down a field, one weighing 180 pounds and the other 150 pounds, the larger player is the more difficult to stop. If two baseballs of the same size and weight are thrown at different speeds, the faster one is the more difficult to stop. Both the football player and the baseball are hard to stop because of momentum which tends to keep them moving. Momentum may be defined as the mass of a moving body times its velocity, or in the form of an equation as follows: $\text{momentum} = MV$.



Ferdinand Hirsh

The sailors in this picture have just fired a large shell from a five-inch gun on board a battleship. What separate forces act upon a shell when it is fired from a gun?

The momentum of an object depends upon the magnitude of the force acting upon the object and the time through which the force acts, or momentum is equivalent to Ft . The product of force and the time through which the force acts, or Ft , is known as the impulse. Since momentum is equivalent to Ft and since, as shown on the opposite page, momentum = MV , then $Ft = MV$, for quantities that are equal to the same quantity are equal to each other. Solving for F (poundals or dynes) in the latter equation, we obtain $F = \frac{MV}{t}$. Earlier we learned that velocity, in accelerated motion, equals acceleration times the time, or $V = at$. Substituting at for V in the equation $F = \frac{MV}{t}$, we obtain $F = \frac{M(at)}{t}$ or $F = Ma$.

The fall of projectiles and bombs. Let us now compare the motion of an object moving horizontally, such as a projectile fired from a gun, with a projectile dropped vertically from the same height.

EXPLORING THE UNIVERSE OF FORCE

Suppose, for instance, that P in Figure 80 represents a projectile fired horizontally and that P_1 represents a projectile dropped from the same height. Projectile P strikes the ground at point B

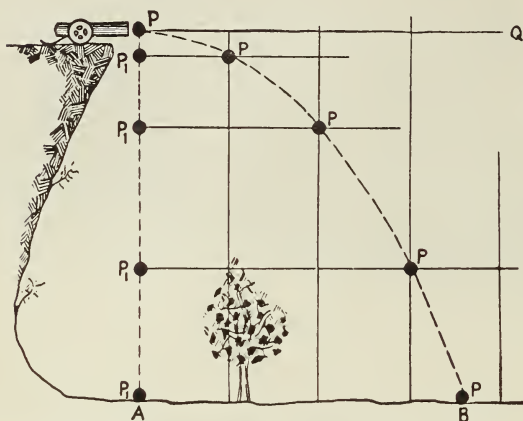


Fig. 80. Rate of fall of freely falling bodies, one projected horizontally and the other dropped vertically.

and therefore travels much farther than projectile P_1 , which hits the ground at point A . From this factor we might easily conclude that projectile P hits the earth sooner than projectile P_1 , but both projectiles reach the ground at identically the same time. Both the projectiles are freely falling bodies; both leave the weapon with no velocity downward;

and both fall the same distance. The one projectile, however, has initial velocity horizontally and its inertia tends to cause it to continue in motion in a horizontal direction, but this horizontal motion has no effect whatever upon its accelerated motion downward. From this illustration we may conclude that when forces tend to move an object simultaneously in different directions, each motion is independent of the other.

Example. A projectile is fired with an initial velocity of 1200 feet per second from the top of a fort 64 feet high. How far from a point directly beneath the point from which it is fired does the projectile strike the ground?

Solution. To solve this problem we substitute 64 feet for S and 32.16 for a in the equation $S = \frac{1}{2}at^2$ as follows: $64 = \frac{1}{2} \times 32.16 \times t^2$. Solving for t in this equation, we obtain 1.99 seconds, which represents the time the projectile travels. Then we multiply the horizontal velocity of 1200 feet per second by 1.99 and obtain 2388 feet, the horizontal distance that the projectile travels.

Example. A bomber travels at a velocity of 200 miles per hour at an altitude of 2 miles. How far from a point directly over a target must the gunner release a bomb in order to score a hit?

Solution. To solve this problem, we convert 2 miles to 10,560 feet and 200 miles per hour to 293.3 feet per second. Next we substitute 10,560 feet for S and 32.16 for a in the equation $S = \frac{1}{2}at^2$ as follows: $10,560 = \frac{1}{2} \times 32.16 \times t^2$. Solving for t in this equation, we obtain 25.62 seconds, the length of time before the bomb reaches the ground. Then we multiply 293.3 feet per second, the velocity of the bomber, by 25.62 and obtain 7516.35 feet or 1.32 miles, the horizontal distance from the target to the point at which the gunner should release the bomb.

The "kick," or recoil, of a gun. Whenever a person fires a gun, he notices that it "kicks," or jerks backward, toward his shoulder. The tighter he holds the gun the less it kicks, because his body helps to counteract the reaction. Also the larger the gun the less it kicks, because the greater weight helps to counteract the reaction. A gun kicks because the explosion acts with the same force upon the gun as upon the bullet. In other words the momentum of the gun is the same as the momentum of the bullet. The bullet travels faster and farther because it weighs less than the gun. If we let W and V represent the weight and velocity, respectively, of the bullet, and W_1 and V_1 the weight and velocity, respectively, of the gun, we may then represent the equality of momentum in the form of an equation as follows:

$$WV = W_1V_1.$$

Example. What kick in feet per second has a gun that weighs 10 pounds and fires a bullet weighing 0.0625 pound with an initial velocity of 800 feet per second?

Solution. To solve this problem, we merely substitute 0.0625 pound for W , 800 feet for V , and 10 pounds for W_1 in the above equation as follows:

$$0.0625 \times 800 = 10 \times V_1.$$

Transposing and collecting, $10 V_1 = 50$.

Therefore

$$V = 5 \text{ feet per second.}$$



This student is rotating a flexible steel hoop, the bottom of which is fastened securely to a spindle and the top of which is free to slide up and down the spindle. Centrifugal force causes the hoop to bulge at the sides and to flatten at the top and bottom.

What forces function in curvilinear motion? Many times in life we are concerned with curvilinear motion, or motion in the direction of a curve. When we throw a stone from a slingshot, for instance, we whirl the stone, causing it to exert great tension upon the string, and then release it so that it sails away abruptly in a straight line. The tension on the string develops because the stone, in accordance with the first law of motion, tends to move away in a straight line. The outward force that an object exerts when it revolves, or the force acting from the center to the circumference of a circle representing the path through which it moves, is known as the centrifugal force. Opposed to this outward force is the inward force that we exert on the string to keep the stone moving in a circle rather than flying in a straight line. This inward force, or the force acting from the circumference to the center of a circle representing the path through which it moves, is known as the centripetal force.

NEWTON'S LAWS OF MOTION

Another illustration of curvilinear motion may be drawn from an automobile rounding a curve on a highway. The centrifugal force tends to cause the automobile to skid, and the centripetal force, which in this case is the friction between the tires and the pavement, tends to hold the automobile on the highway. If the automobile is to travel in safety, the latter force must be stronger than the former. For this reason engineers commonly bank curves to increase the traction.

The centrifugal force of an object in curvilinear motion depends upon three factors: first, the mass or weight of the revolving object; second, the speed with which the object travels; and third, the radius of rotation or the radius of the circle represented by the path through which the object moves. All these factors have been summarized in the form of a law, commonly stated as follows: *The centrifugal force of a rotating object is directly proportional to the mass, or weight, of the object and to the square of the speed, and is inversely proportional to the radius of rotation.* If we let F represent the centrifugal force, M the mass of the rotating object, V the speed of the rotating object, and r the radius of rotation, we may express the law in the form of an equation as follows:

$$F = \frac{MV^2}{r}.$$

The units of force represented by F in this equation are absolute units—poundals if English units are used in the calculation, and dynes if metric units are used. In order to convert poundals into ordinary pounds of force we divide by 32.16 and in order to convert dynes into ordinary grams of force we divide by 980.

Example. If a ball weighing 1 pound is whirled from the end of a string 3 feet long at the rate of 50 revolutions per minute, what is the centrifugal force?

Solution. To solve this problem, we first find how many feet per second the ball moves in its circular path. Applying the equation $C = 2\pi R$, or the equation for obtaining the circumference of a circle, we obtain 942.48 feet, the distance through which the ball travels in one minute. Dividing 942.48 by 60, we obtain

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15.71 feet, the distance through which the ball travels per second. Then substituting 1 for M , 15.71 for V , and 3 for r in the foregoing equation, we obtain the following:

$$F = \frac{1 \times (15.71)^2}{3}.$$

Collecting and solving, $F = 82.26$ poundals.

To obtain regular pounds of force, we divide 82.26 poundals by 32.16 and obtain 2.55 pounds.

Earth flattened at the poles. An interesting illustration of the effect of centrifugal force may be drawn from the earth, or globe. The earth rotates on an axis extending from pole to pole, and for that reason the earth's crust along the equator tends to move outward. Thus we see why the earth is slightly flattened at the poles or why its polar radius, or the distance from its center to one of the poles, is less than its equatorial radius, or the distance from its center to any point on the equator. The centripetal force, or the force that holds the earth together, is the force of gravity. Earlier we learned that objects weigh slightly less at the equator than at the poles because the distance is greater to the center of the earth. Now we find another reason why objects weigh less at the equator; namely, because the centrifugal force acts against the force of gravity.

The cream separator. A very interesting device which operates on the principle of centrifugal force is the cream separator. This machine varies greatly in size, ranging from small hand-operated models used on farms to large power-driven models used in factories and dairies. The essential parts of the machines are rotating disks that turn at the rate of from 5000 to 9000 revolutions per minute. When the milk reaches these disks, the heavier skim-milk particles move to the outside and the lighter cream or butter-fat particles move to the inside. Thus the milk is separated into two liquids, the skim milk flowing out of one spout and the cream out of another. This process is very important, for it simplifies the manufacture of many products.

NEWTON'S LAWS OF MOTION

The centrifugal water pump. Another device that operates on the principle of centrifugal force is the centrifugal water pump. This pump consists of a fanlike wheel with curved blades rotated by an outside force such as a motor. The rotating parts are inclosed in a watertight metal case with an opening near the center of the case to admit water from an outside source and an opening at the edge to carry the water away. When the water flows into the case, the rotating blades hurl it against the outer rim of the case and thus cause it to flow outward with great force. The centrifugal water pump is used extensively in city water systems and in the cooling systems of automobiles.

The governor of a steam engine. A third device that depends upon the principle of centrifugal force is the governor of a steam engine. This device, as shown in Figure 81, consists of two balls mounted on flexible arms, the upper ends of which are fastened by means of a plate to a vertical shaft and the lower ends of which are fastened to a collar free to slide up and down on the shaft. A belt from a wheel of the engine causes the governor to rotate. When the engine increases in speed, the balls pull away from the center, causing the collar to rise and partially to close a valve that controls the flow of steam to the cylinder. With the steam partly cut off, the engine slows down and the governor turns less rapidly. The balls then rotate in a smaller circle and the collar drops down on the shaft, opening the steam valve again. Thus a simple little device regulates the speed of a very powerful engine.

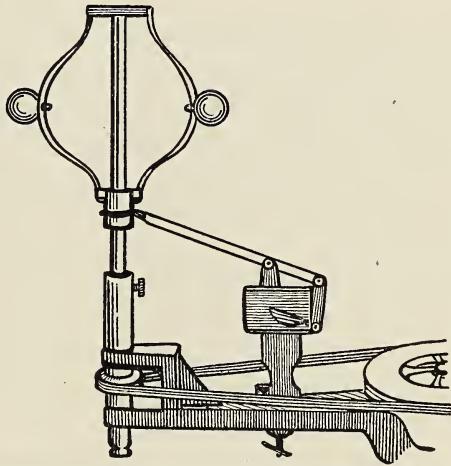


Fig. 81. This drawing shows the governor of a steam engine which acts on the basis of centrifugal force.

EXPLORING THE UNIVERSE OF FORCE

The centrifugal tachometer. A device closely resembling the governor of a steam engine is the centrifugal tachometer that indicates the speed of an airplane engine. This device consists of two or three weights attached to the ends of hinged arms. The reverse ends of the upper arms are attached to a vertical shaft, and the ends of the lower arms are attached to a collar free to slide up and down the shaft. Attached to the collar is a system of levers that turns a pointer on a dial calibrated to show revolutions per minute. The device is rotated by a system of cogs attached to the shaft in the engine. When the speed of the engine increases, the weights pull away from the center and raise the collar on the shaft. The collar, in turn, through the system of levers causes the pointer on the dial to turn farther to the right. When the speed of the engine decreases, the weights rotate nearer the center, the collar falls along the shaft, and the pointer moves to the left.

The rate-of-turn indicator. Turning an airplane to the right or left in flight is somewhat similar to driving an automobile around a curve. The airplane tends to continue in a straight path and hence to skid in the opposite direction from which it is turned. In order to turn an airplane without skidding, the pilot must cause it to set up a bank of air resistance. This he accomplishes by creating an angle, known as the angle of bank, between the plane of the wings and a horizontal plane. The angle of bank causes increased lift upon the wing, one component of which acts as a centripetal force tending to keep the airplane from skidding.

To measure the angle of bank the pilot uses a device known as the rate-of-turn indicator. This device somewhat resembles a gyroscope, or instrument with two like-rotating wheels or disks, one rotating clockwise about a certain axis and the other rotating counterclockwise about an axis perpendicular to the first. When these parts rotate, the device tends to stabilize its position in two planes, one perpendicular to the other. From experience we know that any rotating wheel, such as a flywheel, tends to hold to a uniform position. The rate-of-turn indicator, as shown

NEWTON'S LAWS OF MOTION

in Figure 82, consists of a wheel rotating on axis AB attached to a frame called the gimbal. The gimbal in turn is suspended on pivots at X and Y from a framework attached to the airplane. When the airplane yaws to the right, the B end of the axis of rotation tends to move up and the A end of the axis tends to move down. When the airplane yaws to the left, the ends of the axis move in the reverse direction. An arm attached to the gimbal, through a system of levers, moves a pointer which indicates on a dial the degree of yaw. When the airplane yaws to the right the pointer on the dial moves to the right, showing the degree of yaw, and when the airplane yaws to the left the pointer moves to the left, showing the degree of yaw.

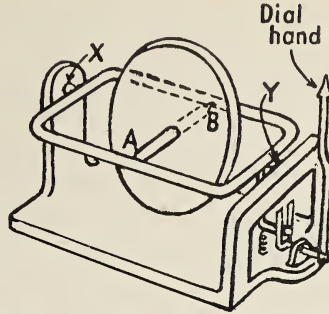


Fig. 82. A diagram of a rate-of-turn indicator showing the two movable parts rotating in perpendicular planes.

The directional gyro. A device somewhat similar to the rate-of-turn indicator is the directional gyro. In this device, however, there are three rotating parts rather than two. These parts rotate on three axes perpendicular to each other and hence rotate in three planes perpendicular to each other. In Figure 83 the rotor turns on axis SW and rotates in plane R , the inner frame turns on axis AB and rotates in plane FF , and the outer frame rotates on pivot D in plane F_1F_1 . The pilot, in using the directional gyro, sets the axis SW so that end W points in the direction in which he is going. Since the parts of

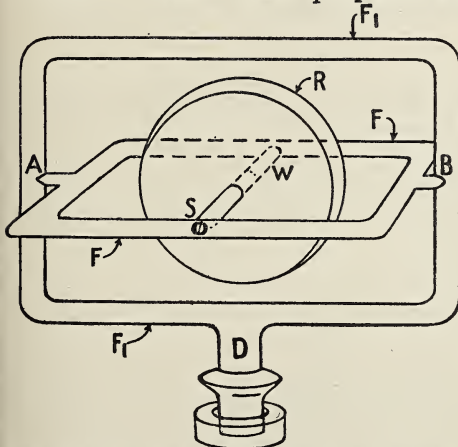


Fig. 83. A diagram of a directional gyro, showing the three parts rotating in perpendicular planes.

EXPLORING THE UNIVERSE OF FORCE

the gyro move in three planes as indicated, the end *W* of axis *SW* continues to point in the direction of flight regardless of whether the airplane yaws to the right or left, ascends or descends, or rolls with one wing higher than the other. Surrounding the working parts of the gyro is a horizontal scale calibrated as is a compass. On the glass in front of the scale is a vertical line known as the lubber line. The scale always holds to the original direction, but the lubber line, being outside the working parts of the gyro, turns with the airplane. Hence by looking at the lubber line the pilot can readily see how many degrees he is flying to the right or the left of the original direction. Such assistance is helpful especially when he cannot see the ground, for he has no other means of determining directions.

ANSWER THESE QUESTIONS

1. What is the first law of motion? What illustrations of the law may be drawn from ordinary experiences of life?
2. What is the second law of motion? To what common situations does this law apply?
3. What is the third law of motion? What is a common illustration of this law?
4. What is meant by momentum? What equation is used in calculating the momentum of a moving body?
5. Why does a gun "kick" when it is fired? How may the kick be calculated?
6. What is centrifugal force? What is centripetal force? How may the centrifugal force be calculated?
7. How does the earth demonstrate the principle of centrifugal force? Why do objects weigh less at the equator than at the poles?
8. How does a cream separator work? How does a centrifugal pump work?
9. How does the governor of a steam engine control the speed of the engine? How does the centrifugal tachometer show the speed of an airplane engine?
10. What is a rate-of-turn indicator? In what way does the instrument resemble a gyroscope? How does it demonstrate the principle of centrifugal force?
11. How does the directional gyro work? How does this device resemble the rate-of-turn indicator?

NEWTON'S LAWS OF MOTION

SOLVE THESE PROBLEMS

A

1. How much force will give a 10-lb. mass an acceleration of 20 ft. per second per second? (Be sure to state the name of the units of the answer.)
2. How much force will give a mass of 20 g. an acceleration of 30 cm. per second per second?
3. What acceleration will a force of 10 poundals give a mass of 20 pounds?
4. If 30 dynes of force act upon 40 g. of mass, what acceleration is produced?
5. If gravity produces an acceleration of 32.16 ft. per second per second, what force in pounds will 20 poundals of force produce?
6. A mass of 10 kg. has a velocity of 98 meters per second. What is its momentum in the metric system?
7. An incendiary bomb that weighs 10 lb. falls freely for 8 seconds after being dropped from an airplane. What is its momentum?
8. Compare the momentum of a football player weighing 200 lb. and running at the rate of 100 yd. in 14 seconds with the momentum of a player weighing 150 lb. and running at the rate of 100 yd. in 10 seconds.
9. If a force of 20 lb. acts upon a freely falling body weighing 100 lb., what is the velocity of the body at the end of 10 seconds?

Every player on a football team develops a certain momentum as he runs down the field, his momentum depending upon his weight and velocity. In order to stop him, another player must exert an equal or greater momentum of his own.

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EXPLORING THE UNIVERSE OF FORCE

B

10. If a shell weighing 20 lb. is fired with an initial velocity of 1800 ft. per second from a cannon having a mass of 2 tons, what is the velocity of the recoil of the cannon?

11. The earth rotates once every 24 hr. on its axis and we assume the radius of the earth to be uniformly 4000 mi. rather than of varying lengths. How much more does a man weigh at the North Pole because of centrifugal force than he weighs at the equator?

12. Compare the centrifugal forces acting upon two automobiles if they are of the same weight and travel around the same curve, but one travels twice as fast as the other.

13. Which has the greater momentum, a 5000-lb. truck traveling at 30 mi. per hour, or a 2300-lb. automobile traveling at 60 mi. per hour?

14. A driver applies the brakes of an automobile weighing 3200 lb. and gives the automobile a negative acceleration of 10 ft. per second per second. If the automobile is traveling at the rate of 50 mi. per hour when the brakes are applied, how far does it go before it comes to a stop?

15. A railroad train weighing 600 tons travels along a level track at the rate of 60 mi. per hour. If the engineer suddenly cuts off the steam, what force must the brakes exert upon the wheels in order to bring the train to rest in 400 feet?

16. An airplane weighing 2500 lb. rounds a pylon at a speed of 110 mi. per hour. If the radius of turn is 200 ft., what is the amount of the centrifugal force?

17. Before landing an airplane a pilot circles the airport to make certain that the runways are clear. What is the amount of the centrifugal force if the airplane weighs 8500 pounds, the speed is 130 miles per hour, and the radius of turn is 3000 feet?

AREA SEVEN

What Forces Affect an Airplane in Flight?

Every machine is affected by forces, some of which help the machine to work efficiently and others of which tend to retard its efficiency. Of the many machines used in modern life, few are affected by more forces than the airplane. This condition prevails because the airplane, as it travels through the atmosphere, is completely removed from the stabilizing influence afforded by the

FORCES AFFECTING AN AIRPLANE

earth. On the following pages we shall see what some of the forces are that affect an airplane in flight. Such study will enable us better to understand the principles of flight and also to appreciate more fully how engineers have applied critical thinking to the problem of handling the forces effectively.

The lift forces of an airplane. The lift forces of an airplane are the forces that tend to raise the airplane or to hold it aloft. In order to understand these forces, let us first consider certain terms that will help to explain how these forces act. Workers in the field of aviation frequently refer to the chord of an airfoil. The chord of an airfoil is an imaginary straight line that represents the length and direction of the airfoil. The length of the airfoil is the straight-line distance from one extremity to another. The direction of the airfoil is the direction in which it points with reference to the wind. The dotted lines in the three drawings in Figure 84 illustrate chords in three forms of airfoil. In the first case the chord passes straight through the center of the airfoil; in the second case it passes along the lower surface; and in the third case it passes outside the airfoil.

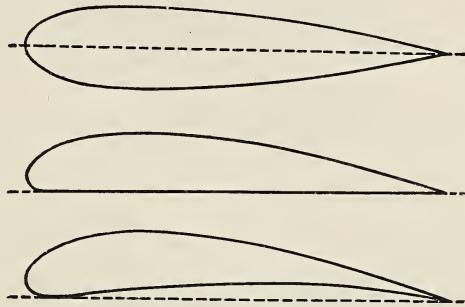


Fig. 84. Chords in three different forms of airfoil.

The angle between the chord of an airfoil and the direction of the wind is known as the angle of attack. The drawing in Figure 85 shows where the angle is situated with reference to a wing. The line CD represents the chord of the wing, and the line AB

represents the direction of the wind. The small angle formed by these two lines, or angle ABC , represents the angle of attack.

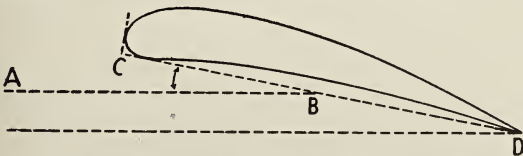


Fig. 85. Angle of attack between the wing and the air.

EXPLORING THE UNIVERSE OF FORCE

The curvature on the surface of an airfoil is known as the camber of the airfoil, and when an airfoil is curved it is said to be cambered. Both the top and the bottom of the airfoil shown in Figure 85 are cambered, one being convex and the other concave.

When an airfoil is convex on one surface and flat or nearly flat on the other as in the case of the wing shown in Figure 86, the air, as we have learned from Bernoulli's principles, moves faster over the camber than it does along the flat surface. This difference in speed brings

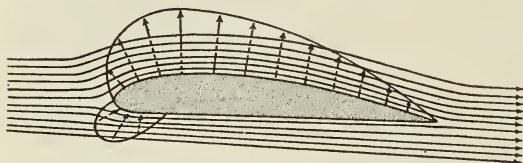


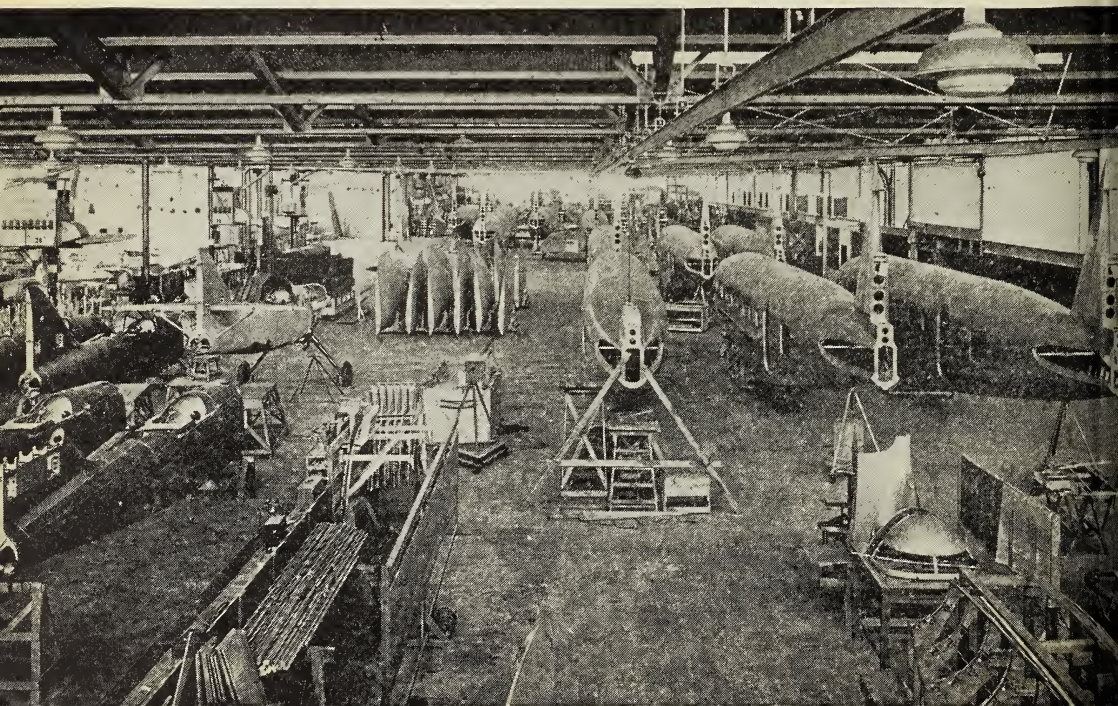
Fig. 86. The left-right lines represent air currents and the arrows show the magnitude and direction of forces.

about greater pressure beneath the wing than above and consequently results in a number of forces that tend to lift the wing. The lifting

forces are represented in the drawing by arrows, the length of the arrows showing the relative magnitude of the forces and the direction of the arrows showing the relative direction of the forces. Where do the forces act with greatest intensity on the wing? In what directions do the forces act?

The picture below shows a section of an airplane factory where parts of the airfoil are assembled. Engineers have carefully designed these parts to secure as great lifting forces as possible and at the same time to minimize the forces of resistance.

Ferdinand Hirsh



FORCES AFFECTING AN AIRPLANE

Calculating the lift on a wing. The resultant of the lift forces on a wing depends upon the angle of attack, the velocity of the airplane, the density of the air, and the area and the contour of the wing. The relation between various angles of attack and wings of various contour has been determined experimentally and expressed in the form of a ratio known as the lift coefficient. The density of the air is expressed in units known as slugs, a slug representing a mass of 32.16 pounds of matter per cubic foot. A cubic foot of air, of course, weighs only a fraction of this quantity, and hence the density of air is only 0.002378 slug per cubic foot at sea level. To determine the resultant of forces causing lift on a wing, we may let L represent the lift, C_L represent the lift coefficient, ρ represent the density measured in slugs per cubic foot, S represent the area of the surface of the wing in square feet, and V represent the velocity of the airplane in feet per second, and indicate the lift in the form of an equation as follows:

$$L = C_L \frac{\rho}{2} S V^2.$$

Example. What is the lift upon the wing of an airplane at sea level traveling at the rate of 90 miles an hour if the lift coefficient is 0.57 and the area of the wing surface is 200 square feet?

Solution. To solve this problem, we convert 90 miles per hour to feet per second, obtaining 132 feet per second. Then we substitute 0.57 for C_L , 0.002378 slug for ρ , 200 for S , and 132 feet in the foregoing equation as follows:

$$L = \frac{0.57 \times 0.002378 \times 200 \times 132^2}{2}.$$

Collecting and

solving, $L = 2361.8$ pounds.

Lift forces affected by angle of attack. As we might judge from the equation for calculating the lift on a wing, the lift forces are greatly affected by the angle of attack. When a wing is set with its chord at an angle as shown in the upper drawing in Figure 87,

EXPLORING THE UNIVERSE OF FORCE

the streamlines are crowded more closely together and the air must therefore move more rapidly than when the wing is set with its chord horizontal. The increased speed of the streamlines above the airfoil reduces the pressure below regular atmospheric pressure

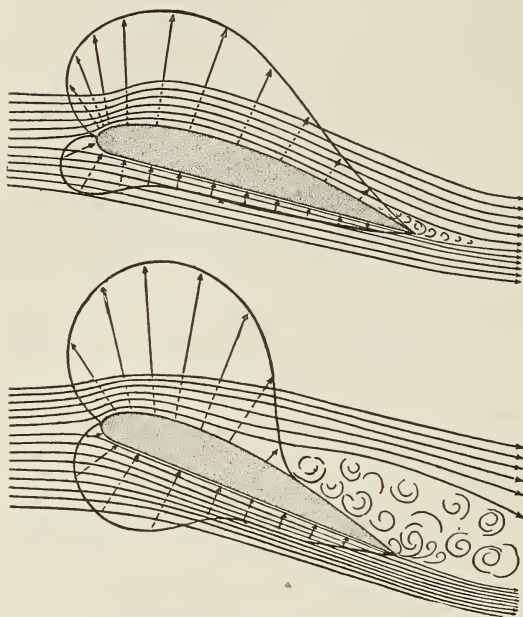


Fig. 87. Diagrams showing how the angle of attack affects the lifting forces acting on the wing of an airplane.

pressure on the upper surface, and many lifting forces act as indicated by arrows. The streamlines below the airfoil hit the wing at an angle, causing many components of force that act upward on the bottom as indicated by arrows. These forces below cause the pressure to rise slightly above regular atmospheric pressure. Thus we see from an analysis of the forces above and beneath a wing that the angle of attack greatly increases the lift of the wing.

Let us now examine the situation when the angle of attack is increased as shown in the lower drawing in Figure 87. In this case the streamlines are so disrupted that they fail to follow the upper surface of the wing entirely to the trailing edge, and an area of low pressure in which burbling occurs is found above and back of the wing. Burbling refers to the forming of eddies as indicated by the curled lines in the drawing. Consequently the forces above the wing that tend to lift the wing, as shown by the arrows in the drawing, affect a smaller area of the wing. This condition, together with the retardation caused by the region of burbling above and back of the wing, causes the wing to have less lift than

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when set at a smaller angle of attack. The lift on a wing increases with the angle of attack up to about 20° , after which burbling begins and the lift decreases as the angle increases.

In order to see more clearly how the angle of attack affects the lift of a wing, let us consider the resultant of forces acting when the wing is set at different angles. When the angle of attack is relatively low, the resultant moves in the direction indicated by the arrow and corresponds quantitatively to the length of the arrow shown in the upper left-hand drawing in Figure 88. When

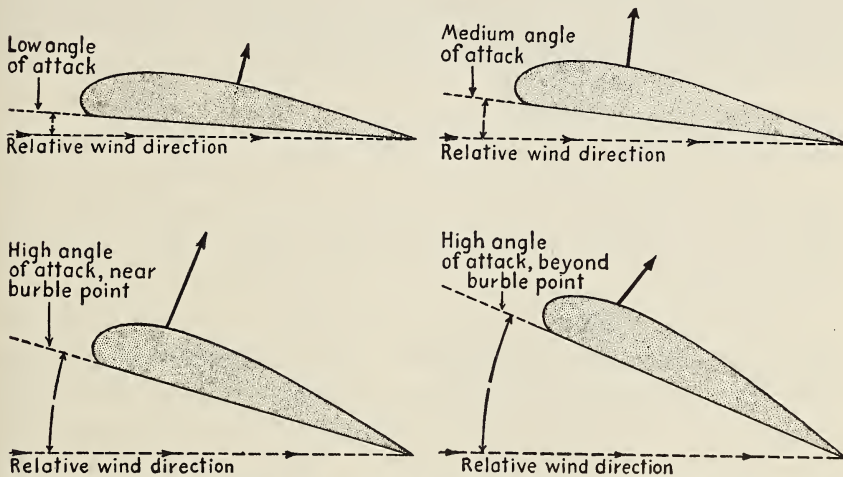


Fig. 88. Diagrams showing how variation in the angle of attack affects the location and strength of the resultant of the lifting forces acting upon the wing of an airplane.

the angle of attack is increased, the resultant shifts to the left and increases quantitatively as shown by the arrow in the upper right-hand drawing. When the angle of attack is increased to near the burbling point, the resultant shifts still farther to the left and reaches its maximum quantitatively as shown by the arrow in the lower left-hand drawing. When the angle is increased beyond the burbling point, the resultant shifts to the right, or begins to move back, and decreases quantitatively as shown by the arrow in the lower right-hand drawing.

EXPLORING THE UNIVERSE OF FORCE

Lift forces affected by velocity. The lifting forces of an airplane are greatly affected by the velocity of the airplane. Hence a pilot depends partly upon the velocity of the airplane to regulate these forces. If he wishes to increase the lift forces, he increases the velocity of the airplane, and if he wishes to decrease the lift forces, he decreases the velocity. When an airplane ascends, as in taking off, the lift forces must be greater than the forces of gravity; when it cruises or flies at a uniform level, the lift forces must equal the force of gravity; and when it descends, as in landing, the lift forces must be less than the force of gravity.

The velocity of an airplane is also an important factor in traveling at high altitudes, as in the stratosphere. Since the lift decreases with density and density decreases with altitude, the pilot must increase the velocity of the airplane to compensate for the loss of lift caused by the decrease in density. Airplanes traveling in the stratosphere must therefore maintain faster schedules than those traveling at lower levels. At the same time the airplane is propelled more easily because there is less resistance from the air.

To determine what velocity is necessary to secure adequate lift, engineers derive an equation from the equation used for determining lift, which we have previously considered; namely,

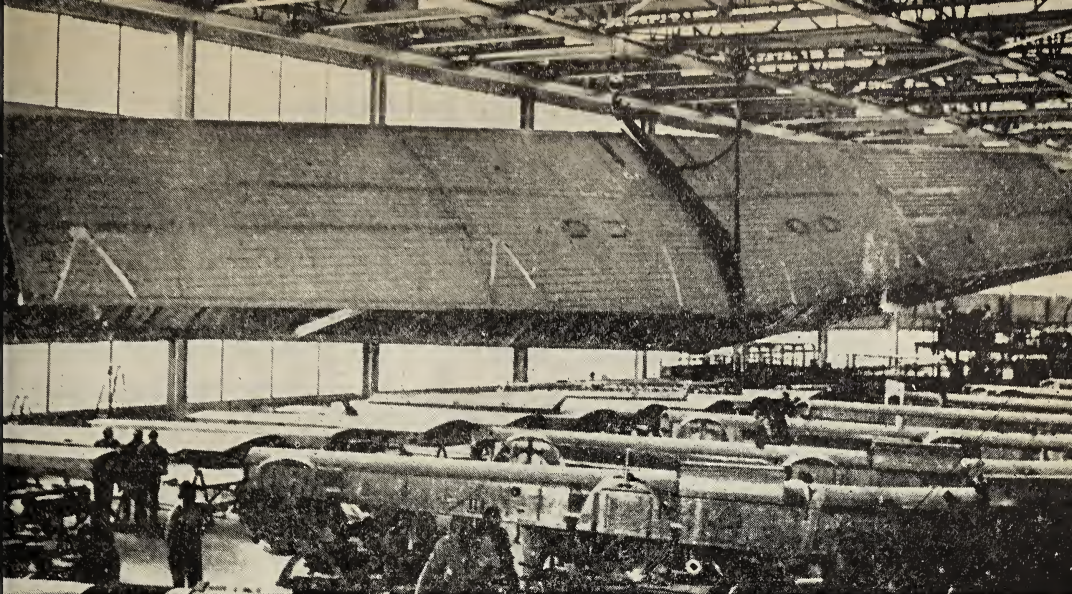
$L = C_L \frac{\rho}{2} S V^2$. In this case, however, they substitute W for L ,

since the weight of the airplane exactly equals the lift when the airplane travels at a uniform altitude. Solving for V in this equation,

they obtain the formula $V = \sqrt{\frac{W}{C_L \frac{\rho}{2} S}}$. In this equation

W , which represents the weight of the airplane, and S , which represents the area of the wings, are constant because the same

airplane is used. Likewise, $\frac{\rho}{2}$, which represents half the number of slugs per cubic foot of air flown through, is constant because the density of air is approximately uniform at one level. Since these three quantities are constant, V , which represents the velocity,



Ewing Galloway

The picture above shows a section of an airplane wing which is being conveyed from one part of an airplane factory to another. After the section has been thoroughly tested in a huge wind tunnel, it will be used as part of the wing of a bomber.

varies inversely as the square root of C_L , the lift component. From this relationship, the pilot can tell exactly how fast he should drive the airplane in order to secure the necessary lift.

Lift forces affected by density. The lift forces are greatly affected by the density of the air through which an airplane travels. We can readily understand why this is true, because the buoyancy of air depends upon its mass, or the number of molecules of which it is composed. Since density of air decreases with altitude, the buoyancy of air decreases, as do the lift forces. The density of air at an altitude of 18,000 feet is only about half as great as at sea level, and therefore the lift forces are only half as great.

Although the lift is relatively low at high altitudes, flying at high altitudes has certain advantages. For one thing, the force of air resistance is reduced, because the air exerts less pressure and is more easily pushed aside. Flying at high altitudes, a pilot can travel above the clouds and therefore avoid many atmospheric disturbances with accompanying pressure changes that cause the plane to rock or to rise or drop abruptly. The region of relatively low density, the lower level of which ranges from six miles above

EXPLORING THE UNIVERSE OF FORCE

the earth at the poles to eleven miles above the earth at the equator, is commonly known as the stratosphere. Many airplanes today find it advantageous to travel in this region.

Lifting forces affected by the size and contour of the wing. The lifting forces are greatly affected by the size and contour of the wing. In general, the larger the wing the greater the lift, because the greater is the surface affected by Bernoulli's principle. Thus a wing with 200 square feet of surface has approximately twice the lift of a wing with 100 square feet of surface provided it has the same shape and the same angle of attack. Whether or not an airplane is built with larger wings depends upon the weight of the airplane and upon the weight of the loads that the airplane is designed to carry. The length and width of the wings may vary, but the total square feet of surface must always bear a direct ratio to the weight of the airplane and its load.

The contour of a wing, like the length and breadth of a wing, also varies, but engineers have determined the most effective camber for various dimensions. The camber on the upper surface must be sufficient to crowd closer together the streamlines and to increase the velocity of the air. In other words, it must be sufficient to provide the necessary lifting forces on the wing. On the other hand, the camber must not be so great as to cause burbling near the trailing edge, for such burbling reduces the surface on which the lifting forces act. By experiment engineers have determined the camber that results in maximum lift.

Overcoming the force of air resistance. One of the chief forces that an airplane must overcome is the force of air resistance. This resistance arises from the fact that air, like all other forms of matter, occupies space and must therefore be split and turned aside as the airplane moves forward. The resistance of air to an airplane is partly overcome by the shape of the airfoils, especially the shape of the fuselage. To understand some of the principles involved, let us see how objects of various shapes are affected when placed in currents of air, as in an air tunnel.

FORCES AFFECTING AN AIRPLANE

When a flat plate is placed in an air tunnel and air is forced past the plate at a moderate rate of speed, the streamlines curve around the plate as shown at the left in Figure 89. If the air is

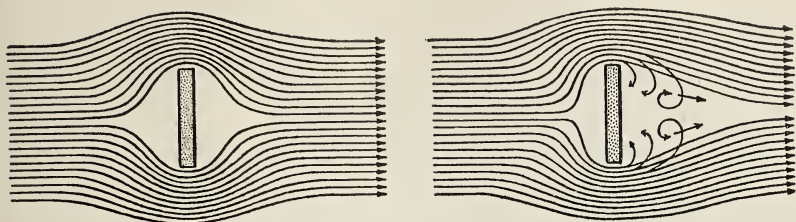


Fig. 89. Streamlines bend abruptly around a plate, especially at great rates of speed.

forced past the plate at a greater rate of speed, the streamlines bend more closely to the plate in front, increasing the pressure at the front as shown at the right in Figure 89. The streamlines close less rapidly in the rear, leaving a region of low pressure back of the plate in which burbling occurs as indicated by the curved arrows in the drawing at the right. The increased pressure at the front of the plate and the decreased pressure back of the plate caused by increased velocity in the streamlines make a great difference in the resistance that the plate offers to the wind.

Now let us see what happens when a sphere is placed in an air tunnel in place of the plate. Such an object offers less resistance because it causes the streamlines to change their direction less abruptly. When air is forced past the sphere at a moderate rate of speed, the streamlines open and close much as shown at the left in Figure 90. If the air is forced past the sphere at a greater rate of speed, however, the conditions are similar to those

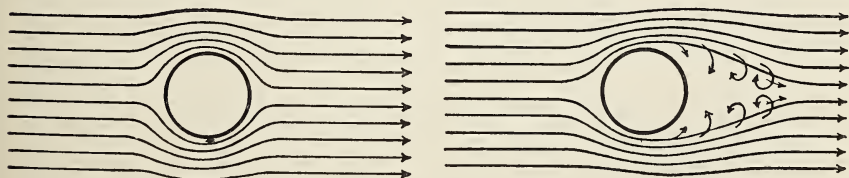
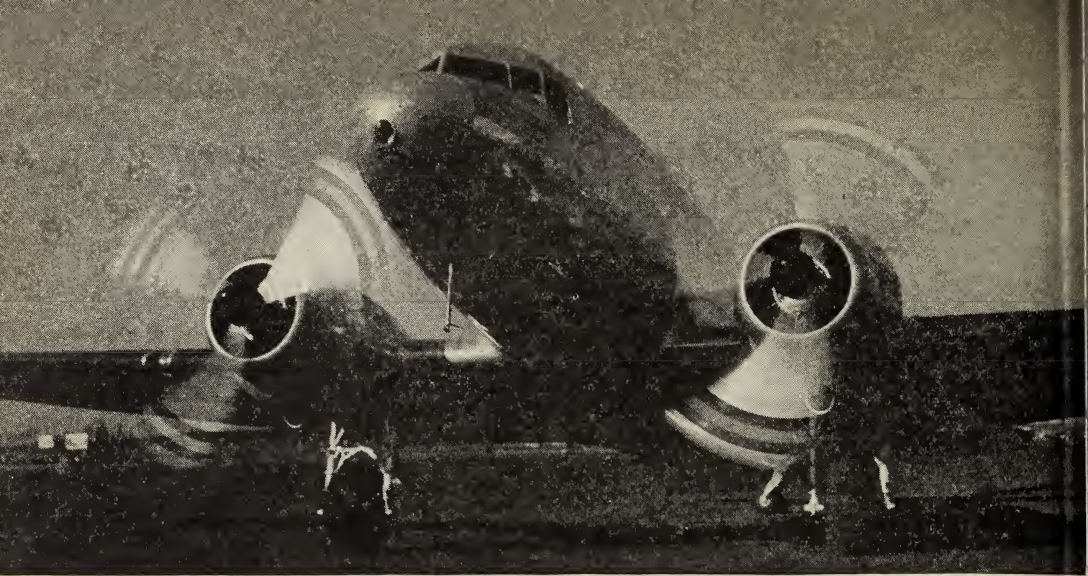


Fig. 90. Streamlines bend less abruptly around spheres than around plates because spheres offer less resistance to air. Which of the drawings shows the effects of burbling?



Ferdinand Hirsh

The fuselage of an airplane is commonly rounded in front and tapered in the rear because engineers have found that such a shape offers least resistance to the air. In general the shape resembles that of the object shown in the drawing below.

when air at increased velocity was forced past the flat plate. At the front the streamlines come more closely to the sphere, increasing the pressure at the front of the sphere. At the rear the streamlines close less rapidly, leaving a region of low pressure back of the sphere in which burbling takes place. Thus increased velocity on the part of the streamlines results in increased resistance on the part of the sphere.

Next let us put into the air tunnel an object rounded in the front like a sphere and tapered in the rear like a cone as in Figure 91. When air is forced past this object, the streamlines at the front follow the same directions as those that we examined in the front of the sphere. In the rear the conditions are completely



Fig. 91. Streamlines bend smoothly around an object rounded in front and tapered in the rear.

changed because the tapered part of the object fills the low-pressure region where the burbling occurred. As a result the streamlines follow closely the shape of the object and the low-pressure area is greatly reduced. Regardless of whether the ve-

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locity is moderate or great, the streamlines follow approximately the same paths, and the object offers much less resistance to the air than either the plate or the sphere.

From the foregoing we can readily see why the fuselage of airplanes is commonly rounded in front and tapered in the rear. Such a slope tends to cut down the resistance of air, especially in the rear where burbling is practically eliminated. The designers of airplanes perform many tests with objects of different shapes to find out what shape of airfoil reduces air resistance most.

Calculating the force of air resistance. When a current of air strikes any flat surface, such as a section of the fuselage or wing of an airplane, it collides with the surface just as any object collides with another when two objects meet. The collision of the wind and the surface causes the wind to lose part of its force at the front. The formation of a low-pressure area with eddy currents at the rear also contributes to the force of resistance. The sum total of the two forces—namely, the force at the front and the force at the rear—exceeds the total force of the wind. Experimental tests show that the sum total is 1.28 times the force of the wind. If the force of resistance exactly equaled the force of the air, we might indicate the force by means of the formula $\frac{1}{2}MV^2$, in which M represents the mass of the air and V represents the velocity. Since the force of resistance is 1.28 times the force of the wind, however, we may indicate the total force by $\frac{1.28MV^2}{2}$.

In calculating M , or the mass of air, engineers commonly use the unit known as a slug, which has already been defined. The mass of air that strikes the plate is equal to the number of slugs times the area of the plate indicated in square feet, or M equals slugs times area. Substituting this equivalent for M in the formula $\frac{1.28 MV^2}{2}$, we may represent the force of resistance in the form of an equation as follows:

$$\text{Force} = \frac{1.28 \times \text{slugs} \times \text{area} \times \text{velocity squared}}{2}.$$

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Example. What force does a wind traveling at a rate of 30 miles an hour exert upon a signboard 20 feet high and 30 feet long when it strikes the signboard perpendicularly?

Solution. To solve this problem, we convert 30 miles per hour into feet per second, obtaining 44 feet per second. Then we substitute in the foregoing equation as follows:

$$F = \frac{1.28 \times 0.002378 \times 20 \times 30 \times 44^2}{2}$$

Collecting and solving, $F = 1769.9$ pounds.

The relation of thrust and drag. The pull of the propeller of an airplane, or the force that moves the airplane forward, is known as the thrust. The force of air resistance that holds the airplane back is known as the drag. Each part of the airplane that is exposed to the air, such as fuselage, wing, fin, landing gears, and the like, has its own drag. The sum of the drags on the various parts makes up the drag for the airplane as a whole. When the thrust is greater than the drag, the airplane gains accelerated motion, or an increase in velocity. When the thrust is equal to the drag, the airplane continues at the same velocity as it had when the forces became equal. When the thrust is less than the drag, the airplane takes on negative acceleration and hence loses velocity.

In determining the drag of an airplane, engineers use the equation for determining lift, except that they substitute C_D , drag coefficient, for C_L , lift coefficient. The drag coefficient is a ratio that shows the relationship between the contour of the wing and the angle of attack. This coefficient varies with different combinations of contours and angles of attack, but has been carefully calculated for the various combinations and made available for determining the drag. Thus if we let D represent the drag in pounds, C_D represent the drag coefficient, ρ represent the density in slugs per cubic foot, S represent the area of the airfoils in square feet, and V represent the velocity in feet per second, we may indicate the equation for determining the drag as follows:

$$D = C_D \frac{\rho}{2} S V^2.$$

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If we analyze the foregoing equation for determining drag, we find that the terms C_D and S in the equation are constant for the same elevation and that $\frac{\rho}{2}$ is approximately constant for the same elevation. Therefore we may conclude that the drag of an airplane varies directly with the square of the velocity.

Summary of the forces affecting an airplane. If we analyze the forces that we have studied thus far, we find that some of them work vertically and others work horizontally. The lift forces that we have studied act upward vertically and thus oppose the force of gravity, which acts downward vertically. The force of thrust acts forward horizontally when the airplane is traveling at a uniform height and opposes the forces of drag, which act backward horizontally. Thus the relation between the lift forces and the force of gravity determines whether the airplane takes on accelerated motion upward or downward. The relation between the force of thrust and the forces of drag determines whether the airplane takes on positive acceleration (increases its speed) or negative acceleration (loses its speed).

Besides the foregoing relation of forces let us also consider the moments of force about the center of gravity. These moments help to determine whether the plane yaws, or turns on its vertical axis to the right or left, or whether it turns on its lateral axis and climbs or pitches. When the sum of the moments is zero in relation to either axis, the airplane tends to travel in the same direction and on the same level.

Summarizing our discussion of forces, we may say that an airplane flies horizontally with uniform velocity when the following conditions obtain: (1) the algebraic sum of the vertical forces equals zero; (2) the algebraic sum of the horizontal forces equals zero; and (3) the algebraic sum of the moments of force about the center of gravity equals zero. On the basis of the direction in which they act and the manner in which they affect various parts, the forces affecting an airplane may be classified according to the table on the following page.

EXPLORING THE UNIVERSE OF FORCE

Upward vertical forces.....	{ Lift of the wings Lift of tail surfaces
Downward vertical forces.....	{ Weights of various parts
Backward horizontal forces.....	{ Drag of the fuselage Drag of the wings Drag of the tail surfaces Drag of the landing gears
Forward horizontal force.....	{ Thrust of the propeller

ANSWER THESE QUESTIONS

1. What forces act upon a kite when it is flying in the air? What component determines whether or not the kite rises, floats at the same level, or falls?
2. What causes lift forces on the wings of an airplane? How are such forces commonly designated in a drawing? How is the lift of a wing calculated?
3. How are the lift forces of a wing affected by the angle of attack? What happens when the angle of attack becomes too great?
4. How are the lift forces of a wing affected by the velocity of the airplane? How do engineers calculate the velocity necessary to secure adequate lift?
5. How are the lift forces of a wing affected by density? What advantages come from flying at high altitudes?
6. How are the lift forces of a wing affected by the size of the wing? by the contour of the wing?
7. An object of what shape offers the least resistance to air? What difference exists in the direction of the streamlines that pass around such an object and the streamlines that pass around a plate or a sphere?
8. How is the force of air resistance calculated? How does the sum total of the forces of retardation on an airplane compare with the force of air resistance?
9. How does the force of thrust affect an airplane? the force of drag? How is the total force of drag calculated?
10. Which forces affect an airplane vertically? Which affect an airplane horizontally? How is the airplane affected by the moments of force about the center of gravity?
11. What conditions obtain with reference to the forces affecting an airplane when the airplane flies horizontally at a uniform velocity?

WHAT AFFECTS THE PERIOD OF A PENDULUM

SOLVE THESE PROBLEMS

A

1. An airplane model that is tested in an air tunnel with the velocity of air at 32 ft. per sec. has a lift of 5 pounds. Other things being the same, what lift would the model have if the velocity of air were 144 ft. per second?

2. An airplane model with a wing area of 12 sq. ft. has a lift of 3 lb. when placed in an air current traveling at the rate of 30 ft. per second. What lift would a similar airplane have if its wing area were 150 square feet?

3. The area of the wing of an airplane is 200 sq. ft., the coefficient of drag is 0.03, the velocity is 220 mi. per hour, and the density of air is 0.0025 slug per cubic foot. What is the drag on the wing?

4. The area of the wing of an airplane is 175 sq. ft., the coefficient of lift is 0.6, the velocity is 180 mi. per hour, and the density of air is normal. What is the lift on the wing?

5. If the area of a section of airfoil on an airplane is 200 sq. ft., the coefficient of lift is 0.7, and the lift is 1500 lb., how fast in miles per hour does the airplane travel at sea level?

6. If the area of a test wing is 200 sq. ft. and the drag is 40 lb. when tested in a current of air traveling at the rate of 45 mi. per hour at sea level, what is the drag coefficient?

7. If an airplane has a lift of 1500 lb. at sea level where the density of air is 0.002378 slug per cu. ft., what lift has the airplane when it rises to an altitude of 1000 ft. where the density of air is 0.001756 slug per cubic foot?

AREA EIGHT

What Forces Act on a Swinging Pendulum?

For a long, long time man has been greatly interested in the pendulum because of the regularity of its swing. This regularity led him to associate the pendulum with the measurement of time, and finally he began to use the pendulum to regulate the movement of clocks. The first person to study the pendulum was Galileo, who experimented with a swinging chandelier in a cathedral at Pisa, timing its vibrations with his pulse.

EXPLORING THE UNIVERSE OF FORCE

Certain definitions associated with the pendulum. In discussing the pendulum scientists commonly refer to an imaginary pendulum, known as a simple pendulum, which consists of a weight called a bob suspended by a weightless cord from a fixed point called the

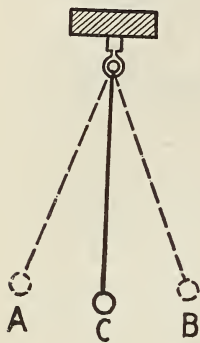


Fig. 92. The vibrations of a simple pendulum.

axis. The nearest approach to such a pendulum is a weight suspended by a very fine thread from a fixed point. The pendulum which we find in use, or any suspended object that moves freely from a fixed point, scientists refer to as a compound pendulum. Thus a meter stick suspended at one end so that it is free to move at the other is a compound pendulum.

A single or simple vibration of a pendulum is the swing from one position and direction to the opposite position and direction as from A to B in Figure 92. A complete vibration is double a single vibration, or the swing from one position and direction to the opposite position and direction and back again, as from A to B and back to A. The amplitude is the largest displacement of the bob of the pendulum from its position of rest, as the distance along the arc from C to A or the distance along the arc from C to B. The period of vibration is the time required in seconds for one complete vibration. The frequency is the number of complete vibrations per second.

What causes a pendulum to swing? A pendulum swings because it is acted upon by a component of the force of gravity. Suppose that the pendulum in Figure 93 is drawn to the left so that its amplitude is AA_1 . The force of gravity, A_1G_1 , the diagonal of the parallelogram, then consists of two components, A_1R_1 which causes a tension on the string and A_1B_1 , perpendicular

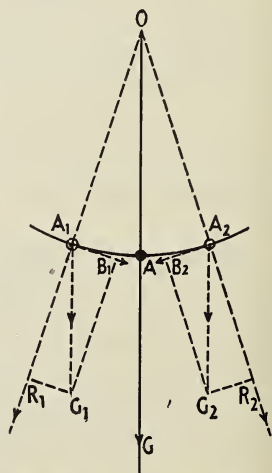


Fig. 93. Two component forces act on a swinging pendulum.

WHAT AFFECTS THE PERIOD OF A PENDULUM

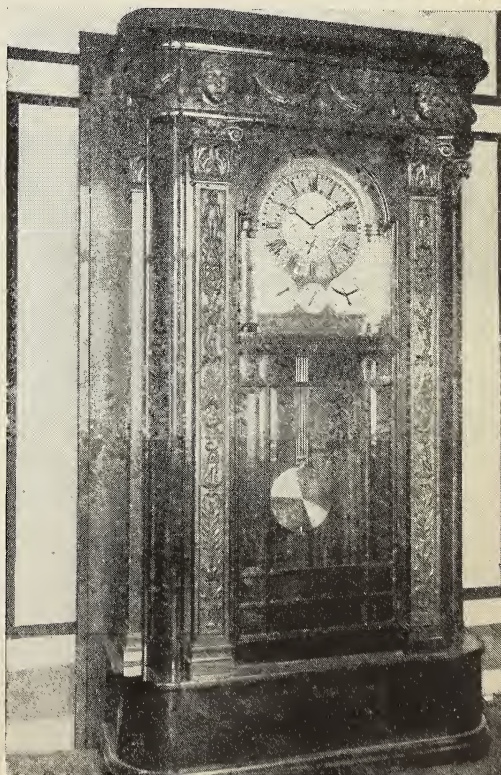
to A_1R_1 , which causes the pendulum to swing toward the vertical position OA . As the pendulum moves toward the vertical position, the component that causes tension on the string increases and the component that pulls the pendulum toward the center decreases. When the pendulum reaches the center, the latter component becomes zero but the inertia of the bob causes the pendulum to swing on to the right. As the pendulum continues to the right, one component of gravity causes tension on the string and the other retards its movement. Finally, the latter component, represented by A_2B_2 , completely stops the pendulum and causes it to start back to the vertical position OA . Thus the forces continue so long as the pendulum swings.

The laws of the pendulum. If we pull a pendulum aside 10 degrees and measure the time required for a complete vibration and then pull the same pendulum aside 5 degrees and measure the time required for a complete vibration, we find that the time is approximately the same. Ordinarily, in determining the period of a complete vibration we find the time required for 100 vibrations and divide by 100. The first law of the pendulum is commonly stated as follows: *When the arc is small, the period is independent of the amplitude.*

If we swing with the same amplitude two pendulums of the same length, one with a bob made of a dense substance, such as lead, and the other with a bob made of a less dense substance, such as aluminum, we find that the periods of the pendulums are the same. Even if we change the size of the bobs, the periods remain the same. This experiment explains the second law of the pendulum, which is stated as follows: *The period of a pendulum is independent of the mass of the bob.*

The accuracy of this grandfather clock depends upon the regular swing of the pendulum.

Ferdinand Hirsh



EXPLORING THE UNIVERSE OF FORCE

If we measure the period of a pendulum 25 centimeters long (from the axis to the center of gravity of the bob), as represented by the pendulum at the left in Figure 94, and then measure the

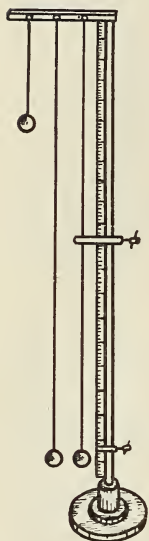


Fig. 94. Simple testing stand for pendulums.

period of a second pendulum 100 centimeters long, as represented by the pendulum in the center of the drawing, we find that the period of the second pendulum is twice that of the first. Since the square root of 100 is 10 and the square root of 25 is 5, the periods are directly proportional to the square roots of the lengths. Hence the third law of the pendulum may be stated as follows: *The period of a pendulum is directly proportional to the square root of the length.*

If we compare the periods of two pendulums of the same length, as those shown at the right in Figure 94, with the acceleration caused by gravity (commonly expressed as g) we find that the periods are inversely proportional to the square root of the acceleration. This finding leads to a fourth law of the pendulum which is stated as follows: *The period of a pendulum is inversely proportional to the square root of the acceleration due to gravity.*

Calculations based on the pendulum. If we let t represent the time in seconds required for one complete vibration of a pendulum, l the length of the pendulum, and g the acceleration due to gravity, we may express the time of a vibration in the form of an equation as follows: $t = 2\pi\sqrt{\frac{l}{g}}$. If we know the value of t and the

value of g , we may also use the equation for finding the value of l . Likewise if we know the value of t and the value of l , we may use the equation for finding the value of g , which we ordinarily consider 32.16 feet per second per second, but which, as we have learned, varies slightly at different locations on the globe.

Example. How long must an ordinary pendulum be in order to beat seconds; that is, to make a simple vibration in one second or a complete vibration in two seconds?

WHAT AFFECTS THE PERIOD OF A PENDULUM

Solution. To solve this problem we substitute 2 seconds for t and 980 centimeters for g in the foregoing equation as follows:

$$2 = 2\pi\sqrt{\frac{l}{980}}.$$

Transposing and solving, $l = 99.29$ centimeters.

Example. What acceleration of gravity at a certain location on the earth's surface acts on a pendulum 100 centimeters long when the time required for one complete vibration is 2.008 seconds?

Solution. To solve this problem we substitute 2.008 seconds for t and 100 centimeters for l in the foregoing equation as follows:

$$2.008 = 2\pi\sqrt{\frac{100}{g}}.$$

Transposing and solving, $g = 979.09$ centimeters.

The use of a pendulum in a clock. When a freely moving pendulum swings in the air, it gradually comes to rest because it meets resistance from the air. Consequently, when a pendulum is used to regulate the movement of a clock, a mechanical device, known as an escapement, is required to keep the pendulum swinging. A lever of the escapement, indicated by A in Figure 95, is attached to the pendulum and a wheel indicated by B is attached to the spring of the clock. As the pendulum swings it causes first one end of the lever and then the other to catch between the teeth of the wheel. The wheel thus transmits impulses or bits of force to the lever which are passed along to the pendulum and keep the pendulum swinging. The speed of the clock may be regulated by means of a thumbscrew that raises or lowers the bob on the pendulum. If the clock runs too fast the bob must be lowered on the pendulum and if it runs too slow the bob must be raised. The spring in the clock must be wound from time to time to keep the clock going.

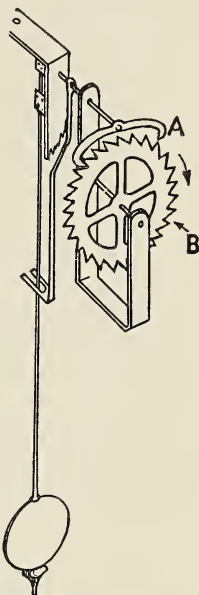


Fig. 95. The parts of a simple escapement.

EXPLORING THE UNIVERSE OF FORCE

ANSWER THESE QUESTIONS

1. What is meant by a simple pendulum? What is meant by a compound pendulum?
2. What is a single or simple vibration of a pendulum? What is a complete vibration?
3. What is the amplitude of a pendulum? What is the period of vibration? What is the frequency?
4. What component of gravity causes a pendulum to swing? What component causes tension on the string?
5. What are the laws of the pendulum? What experiment may be performed to illustrate each law?
6. What equation is used in making different calculations based on the pendulum? What quantities may be found through the use of this equation?
7. How does the escapement on a clock cause the pendulum to keep swinging?

SOLVE THESE PROBLEMS

1. If a swinging pendulum makes 100 complete vibrations in 5 min., what is its period?
2. If a swinging pendulum is 100 cm. long and the acceleration of gravity is 980 cm. per second per second, what is its period?
3. How many feet long must a pendulum be in order to make one complete vibration in 4 sec., if the value of gravity at this location is 32.16 ft. per second per second?
4. What is the value of gravity if a swinging pendulum 100 cm. long has a period of 2.01 seconds?
5. If a swinging pendulum has a period of 2 sec. and is one-fourth as long as a second swinging pendulum in the same location, what is the period of the second pendulum?
6. How long, in centimeters, must a pendulum be in order to beat seconds?
7. If a swinging pendulum makes 100 vibrations in one min. and another swinging pendulum makes 80 vibrations in one min. how do their lengths compare?
8. A weight swings on the end of a rope 1000 ft. long. What is the period of the weight if the value of gravity at this location is 32.16 ft. per second per second?
9. What is the value of gravity in the metric system at a certain location on the earth if at this location a swinging pendulum 95.3 cm. long has a period of 1.04 seconds?

SUMMARY

The molecules in all forms of matter exert force. One cause of this force is the motion of the molecules, which in general is greater in gases than in liquids and greater in liquids than in solids. When molecules of two or more substances mix because of the movement of the molecules, the process is called diffusion. When molecules of one substance move through a membrane and mix with the molecules of another substance, the process is called osmosis. Pressure occurs on the sides of a container because the motion of molecules causes them to bombard the sides. In many instances, especially in the case of gases, the movement of molecules increases with temperature.

Another cause of molecular force is the attraction between molecules. This attraction depends upon the mass of the molecules and their distance apart. If the molecules are alike, the force existing between them is called cohesion. If the molecules are unlike, the force existing between them is called adhesion. Some other properties of materials due to molecular attraction are elasticity, malleability, hardness, and ductility. The distortion after which a material does not resume its original position when the distorting force is removed is called the elastic limit. Hooke's law states that within the elastic limit the elongation is directly proportional to the stretching force. Surface tension is the tendency for surfaces of all liquids to contract and become as small as possible. The rising or falling of the surfaces of liquids in small tubes is commonly known as capillarity.

Gravitation is the attraction of one body for another. Sir Isaac Newton stated that every particle of matter in the universe attracts every other particle with a force directly proportional to the product of their masses and inversely proportional to the square of the distance between their centers of masses. Gravity is a special name given to the force that exists between the earth and objects on or near its surface. Gravity determines the weight of a body and the quantity of materials determines the mass of a body. A moment of force is the product of the force and the perpendicular distance from the force to the fulcrum of a lever.

EXPLORING THE UNIVERSE OF FORCE

Equilibrium exists when the sum of the vertical and horizontal forces acting upon a body is zero and the sum of the moments of force about its axis is zero.

Forces are represented by straight lines. Parallel forces act in parallel directions. The effective force, or resultant, of parallel forces is the sum of the forces when they act in the same direction and the difference between them when they act in opposite directions. The effective force, or resultant, of two forces acting at an angle to each other is the diagonal of a parallelogram whose adjacent sides represent the two forces. The equilibrant of two forces represents the combined effect of the forces moving in the opposite direction. A component of a force is the effective part of the force that acts in a given direction.

Uniform accelerated motion is produced by a constant force acting upon a body. The force of gravity causes a falling body to accelerate approximately 32.16 feet or 980 centimeters per second per second. The velocity of a uniformly accelerated body during any given interval of time equals the acceleration multiplied by the time. The space over which a uniformly accelerated body, starting from rest, moves during a given interval of time equals one-half the product of the acceleration and the time squared.

Newton's laws of motion are stated as follows: (1) A body at rest tends to remain at rest or a body in motion tends to move in a straight line with uniform velocity unless acted upon by some outside force. (2) Change of momentum is equal to the impulse and takes place in the direction in which the force is applied. (3) To every action there is an opposite and equal reaction.

Centrifugal force is the force that tends to cause a rotating object to move away from the center of rotation, as a stone in a sling. Centripetal force is the force that counteracts the centrifugal force, or the force that tends to keep a rotating object in its curved path. The magnitude of these forces may be found by dividing the product of the mass of the rotating object and its velocity squared, by the radius of its path.

The forces that act on an airplane in flight may be classified as follows: (1) the forces that tend to raise the airplane, or up-

ward vertical forces known as lift; (2) the force that tends to pull the airplane toward the earth, or downward vertical force known as gravity; (3) the force that tends to carry the airplane forward, or forward horizontal force known as thrust; and (4) the force that tends to retard the forward progress of the airplane, or the backward horizontal force known as drag.

A pendulum is defined as a body suspended so that it is free to swing about a fixed point called the axis. The vibration of a pendulum is the swing of a pendulum from one position and direction back to the same position and direction. The period is the time required to make one complete vibration. The frequency is the number of vibrations per second. The amplitude is the largest displacement of the bob from its rest position. The period is independent of the amplitude and mass and varies directly as the square root of the length and inversely as the square root of the value of gravity.

Why does the odor from a moth ball or an open bottle of perfume spread throughout a closed room?

Why is your finger wet when placed in water but dry when placed in mercury?

Why have beam balances replaced most of the spring balances that were formerly used in grocery stores?

Why do raindrops tend to be spherical in shape?

Why do farmers till the soil around hills of corn?

Why would you expect your weight at the North Pole to be different from your weight at the equator?

How is it possible for a sailboat to reach a point located in the direction from which the wind is blowing?

Why do modern automobiles have a faster pick-up, or acceleration, than automobiles formerly had?

Why is a person thrown forward when an automobile in which he is traveling suddenly comes to a stop?

Why do long-range guns, such as rifles, always have a long barrel rather than a short one?

What keeps an airplane in the air during flight?

What causes a gun to have a recoil?

If other conditions besides altitude are the same, why would you expect a pendulum clock to run somewhat faster on a mountain than in a valley?

EXPLORING THE UNIVERSE OF FORCE

SOLVE THESE PROBLEMS

1. A spring balance elongates $\frac{1}{4}$ in. when a 5-lb. weight is placed upon it. How far will it elongate when a 40-lb. weight is placed upon it?
2. Two forces of 60 and 80 lb. respectively act from the same point at right angles to each other. What is the resultant force?
3. Without consideration of air resistance, how far will a balloonist fall after he "bails out" before he pulls the cord to open the parachute if the interval of time between the two acts is 3 seconds?
4. A projectile that weighs 640 lb. is shot from the muzzle of a gun with a velocity of 3200 ft. per second. If the barrel of the gun is 32 ft. long, what is the average force exerted by the expanding gas in the barrel? What is the time required for the projectile to go through the barrel?
5. If a pendulum is 99.4 cm. long and requires 2 sec. to make one complete vibration, what is the value of gravity?
6. If an airplane weighs 2000 lb., has a lift coefficient of 0.6, and the area of the wings is 300 ft., what velocity in miles per hour is required to keep the airplane in the air if the atmospheric pressure and temperature are standard?

INVESTIGATIONS

1. Obtain sales literature from an automobile company and notice the explanation of why springs are elastic.
2. When driving an automobile upon a level road free from traffic, push down the accelerator a certain distance and hold it to the same level. Notice by the readings on the speedometer that acceleration increases for a short period of time and then ceases. Find out why the acceleration ceases.
3. Notice how highways are banked around curves and explain why they are built in this manner.
4. Examine a cream separator to find out how it works.
5. Find out how the speed of a steam engine or a phonograph is regulated.
6. Examine a centrifugal clothes drier and explain how it works.
7. Observe the pendulum of a large clock and check its length, amplitude, and frequency.
8. Observe the reaction of a model plane to the air in an air tunnel.
9. Visit an airport and notice how the parts of an airplane are adapted to the various forces acting upon them.
10. Talk with a flyer and find how he controls an airplane.



The farmer in this picture is using a tractor to pull a gang of plows. Every machine, such as a tractor, is of benefit to man because it transfers energy from one form to another.

UNIT FOUR

Energy and the Vehicle upon Which Energy Rides

MEN OF IRON

Years ago man had no such machines as those shown in the picture above. He cultivated the soil only with simple hand tools that required very difficult work. After a time the plow was invented and he was able to use horses or other domestic animals to cultivate the land. Finally the tractor came along, and the efficiency of man's work was multiplied manyfold.

ENERGY AND ITS VEHICLE

This story of progress is representative of the progress that has come in every field of endeavor because of the invention of machines. These machines have enabled man to do more and better work with less effort in the same length of time. With a tractor, for instance, the farmer plows as much land in one hour as he formerly plowed in a day. With a modern printing press a pressman prints as many sheets in one hour as he formerly printed in two days. With an automobile a man travels as far in one day as he formerly traveled in two weeks in a horse-drawn vehicle.

The use of machines has come about because man has applied critical thinking to the problem of doing work. Through critical thinking he has found ways of changing energy from one form to another. In the case of the tractor he has converted the energy of gasoline into energy for pulling machinery. In the case of the printing press he has converted the energy of electricity into energy for pressing plates of metal against sheets of paper.

This unit will enable you to study simple machines in which energy is changed from one form to another. Such study will be helpful because larger machines, such as the tractor and the printing press, are combinations of simple machines.

AREAS OF STUDY

- 1. How does the scientific meaning of work apply to common experiences?*
- 2. How is the rate of doing work measured?*
- 3. What is meant by conservation of energy?*
- 4. How do machines aid man in doing work?*
- 5. How are the mechanical advantages of different machines measured?*
- 6. How is friction controlled?*
- 7. How is the efficiency of machines measured?*

AREA ONE

How Does the Scientific Meaning of Work Apply to Common Experiences?

Work is accomplished when a force moves some object or body through linear space, or distance. If a man lifts a lump of coal, work is done. Other examples of work are the pulling of a plow through the ground, the throwing of a ball, and the flying of an airplane. If the coal, the ball, and the airplane are merely held up by forces without being caused to move, work is not done because the forces do not move them any distance at all. Only when a force moves some object through space is work done.

Definitions of work units. The work that a man or a machine does may be measured just as accurately as the distance from one point to another. By work we mean force times the distance through which the force acts. If W stands for work, F stands for force, and S stands for the linear space, or distance, through which the force acts, then $W = FS$.

A unit of work is always named according to the unit of force that brings the work about and the distance through which the force acts. As we recall, the units of force are of two kinds, gravitational units and absolute units, and consequently we have two kinds of work units; namely, gravitational and absolute. The gravitational units of force most commonly used are the pound and the gram and from these units we obtain the units of work known as the foot-pound and the gram-centimeter. The foot-pound may be defined as the work done when a force of one pound moves through a distance of one foot. The gram-centimeter is the work done when a force of one gram moves through a distance of one centimeter. Both these units of work, like the gravitational units of force from which they are derived, vary slightly at different locations on the surface of the earth because of variations in gravity.

The absolute units of force are the poundal and the dyne and from these units we derive the units of work known as the foot-

ENERGY AND ITS VEHICLE

poundal and the dyne-centimeter. The foot-poundal may be defined as the work done when a force of one poundal acts through a distance of one foot. The dyne-centimeter is the work done when a force of one dyne acts through a distance of one centimeter. The dyne-centimeter, which is also called an erg, is exceedingly small, being only one-980th part of the gravitational unit gram-centimeter. Because of this fact engineers commonly employ a much larger unit in its place, known as the joule, which is equivalent to 10,000,000 ergs. The latter unit is named after the name of its originator, a noted English physicist by the name of James Prescott Joule. All these work units are of fixed value because they have no relation to the force of gravity.

Now let us observe how the definition of work applies to daily experiences. When a man digs a ditch, he gets paid for the work he does because he uses force to lift the dirt. When he fills a truck with coal, he uses force to lift the coal into the truck. The more dirt he throws from the ditch and the more coal he shovels into the truck, the more work is done. The transportation cost of freight is more when the distance is many miles than when it is a few miles because the same force is required to move the freight farther. Likewise, the cost of transportation is more for

The army jeep shown in this picture is a powerful and sturdy means of transportation. All conveyances used in modern warfare must have powerful engines and be of sturdy construction. Each machine must have the capacity for doing a great deal of work.

U. S. Army Signal Corps



SCIENTIFIC MEANING OF WORK

a larger quantity of freight than for a smaller quantity because more force is required to haul the larger quantity. These and similar examples that we can cite from our own experiences show that many features of our economic world are based upon the definition of work. The following examples illustrate how to calculate the amount of work done when a force moves through space.

Example. How much work is required to lift a 50-pound weight 100 feet vertically?

Solution. The force required to lift a 50-pound weight vertically is 50 pounds. Since $W = FS$, then $W = 50 \times 100 = 5000$ foot-pounds of work.

Example. How much work is required to haul 3 tons of coal one mile in a truck if 500 pounds of force is required to move each ton of coal?

Solution. As stated in the problem, only 500 pounds instead of 2000 pounds are required to move each ton because it is moved horizontally rather than lifted vertically. The force required to move 3 tons is $500 \times 3 = 1500$ pounds. One mile equals 5280 feet. $W = FS$. $W = 1500 \times 5280 = 7,920,000$ foot-pounds of work.

Example. How many ergs of work are required to lift 10 kilograms vertically 2 meters? how many joules?

Solution. Since an erg is the product of a dyne and a centimeter, the force 10 kilograms (the force required to lift 10 kilograms of mass vertically) is changed into dynes and the meters into centimeters. $10 \text{ kilograms} = 10 \times 1000 \times 980 = 9,800,000$ dynes of force. $2 \text{ meters} = 2 \times 100 = 200$ centimeters. $W = FS = 9,800,000 \times 200 = 1,960,000,000$ ergs of work. We change this to joules by dividing the ergs by 10,000,000 (the number of ergs in one joule). $1,960,000,000 \div 10,000,000 = 196$ joules of work.

ANSWER THESE QUESTIONS

1. What is the scientific meaning of work?
2. Why is work done when a book is lifted from the floor to the top of a desk?
3. Is it work to move a book from the top of the desk to a lower position on the floor? Why?

ENERGY AND ITS VEHICLE

4. Why would work be done if the book fell from the top of the desk to the floor? What does the work?

5. Which requires more work, to lift a book vertically or to move it over a smooth surface the same distance? Why?

6. Why is work done when the kitchen floor is scrubbed?

7. Who does more work, the man who carries the brick from the ground to the third floor or the brick mason who lays the brick? Why?

8. Why is work done when a person climbs a hill?

9. Who does more work, a large man or a small man when both men climb the same stairs? Why?

10. Why does an elevator do more work when it carries a certain number of grown persons up ten stories of a building than when it carries the same number of children up ten stories?

11. How does the term *work* apply to moving machinery or automobiles?

SOLVE THESE PROBLEMS

A

1. How much work is done in lifting a 2-lb. book from the floor to the top of the desk, a distance of 3 feet?

2. How much work is done in carrying a ton of coal up a stairway 3 ft. high?

3. How much work is done when 1000 cu. ft. of water is raised 50 feet? The water weighs 62.4 lb. per cubic foot.

4. How much work does a 5-ton truck do if it moves 1 mi. over a level road and 200 lb. of force is required to move it?

5. A 120-lb. boy climbs a flagpole 50 ft. high. How much work does he do?

6. How many ergs of work are required to lift 100 g. vertically 50 centimeters?

7. How many ergs of work are required to lift 100 kg. vertically 50 meters? How many joules?

8. How much work is required to haul 50 tons of coal 5 mi. if 200 lb. of force are needed to move each ton? How much work is required if 500 lb. of force are needed to move each ton?

B

9. What force will do 5,000 foot-pounds of work if the body moves 50 ft. and the force is parallel to the direction of the body?

RATE OF DOING WORK

10. How many foot-pounds of work does a team of horses do if they pull a plow 1 mi. per hr. for 8 hr. when the force required to pull the plow is 200 lb. and acts in the same direction in which the plow moves?

11. Calculate the actual work a 120-lb. boy does when he makes 20 trips to carry 1,000 lb. of coal up a stairway 10 ft. high. Find the useful work done.

12. How many joules of work will be required to lift 80 kg. vertically 100 meters?

13. A belt exerts a 10-lb. force upon a pulley 1 ft. in diameter. The pulley is running 200 r.p.m. (revolutions per minute). How much work is done in 10 hours?

14. A car weighing 4000 lb. is loaded with 4000 lb. of coal and is hoisted up the shaft of a mine 400 ft. deep. How much work is done?

15. How much work is done when a punch that exerts a pressure of 40 tons per sq. in. is punched through a plate $1\frac{1}{2}$ in. thick and punches a hole 2 in. in diameter?

AREA TWO

How Is the Rate of Doing Work Measured?

The same amount of work is required to haul a carload of coal 100 miles in 10 hours as is required when only 4 hours are taken. That is, the amount of work does not depend upon the time required to complete it. When work and time are involved, power is used to tell how much work is done in a given time. Power is the rate of doing work. More power is required to do the same work in less time. $\text{Power} = \frac{\text{work}}{\text{time}}$. If P stands for power, W for

work, and t for time, $P = \frac{W}{t}$. But work is equal to force $\times$ space.

Hence $P = \frac{F \times S}{t}$.

Units of power. The horsepower is a unit of power. One horsepower, often abbreviated HP., is defined as 33,000 foot-pounds of work per minute or 550 foot-pounds per second. A 50-horsepower engine, for example, is capable of doing 33,000 foot-pounds $\times$ 50, or 1,650,000 foot-pounds of work in one minute.

ENERGY AND ITS VEHICLE

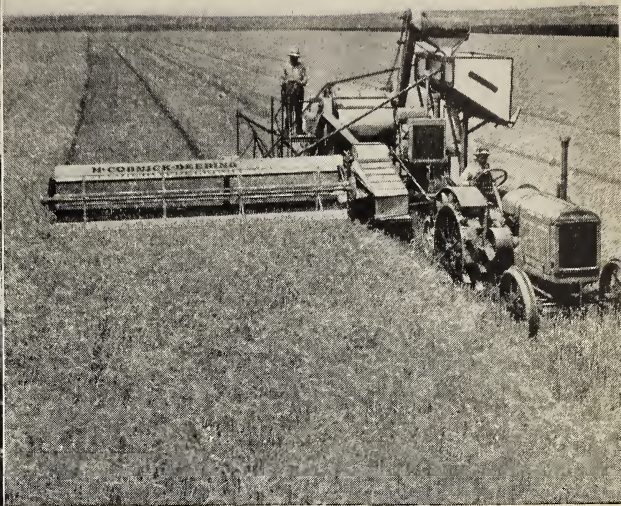
The first man to experiment with units of power was James Watt, the famous English scientist and instrument maker who invented the steam engine. This eminent scientist experimented with a large horse and found that it could do about 33,000 foot-pounds of work in a minute. In other words, it could do the equivalent work of lifting 33,000 pounds through a distance of one foot or one pound through a distance of 33,000 feet. The average horse used on a farm, however, does about three-fourth horsepower of work. For a short period of time, of course, a horse may develop a greater horsepower, as when it runs a race. An average person does only about one-seventh horsepower of continuous work but, like a horse, may develop a greater horsepower for a short period of time. Even though horsepower is based on foot-pounds, it is a gravitational unit and hence varies slightly from place to place.

Besides determining the gravitational unit of power known as horsepower, Watt also determined an absolute unit known as the watt. This unit is equal to 10,000,000 ergs or the power required to do one joule of work per second. Since this unit is an absolute unit, and hence not affected by the force of gravity, its value is fixed. To standardize the relation between the unit horsepower (HP.) and the unit watt, the National Bureau of Standards has established the horsepower as 746 watts. Since the watt is a rather small unit, the kilowatt (kw.) which includes 1000 watts is commonly used in its place. Thus we may redefine the horsepower as 0.746 kilowatt, which is approximately 0.75 kilowatt.

The horsepower unit and the watt unit are determined in accordance with the following equations:

$$\text{HP.} = \frac{\text{foot-pounds}}{33,000 \times \text{minutes or } 550 \times \text{seconds}}, \text{ or } \text{HP.} = \frac{\text{watts}}{746}.$$
$$\text{Watts} = \frac{\text{dyne-centimeters or ergs}}{10,000,000 \times \text{seconds}} = \frac{\text{joules}}{\text{seconds}}.$$

Example. How many horsepower are required to lift within a period of 2 minutes an elevator carrying a load of 2250 pounds to the fortieth story of a building if each story is 15 ft. in height and the elevator weighs 1000 pounds?



Ferdinand Hirsh

The term horsepower was determined from the work of a horse. The left-hand picture shows Cyrus McCormick walking behind his horse-drawn reaper. The picture at the right shows a modern reaper pulled by a tractor that develops many horsepower.

Solution. First we multiply 600 feet, the distance traveled by the elevator, by 3250 pounds, the combined weight of the elevator and the load, and obtain 1,950,000 foot-pounds. Then we substitute in the foregoing equation for horsepower, as follows:

$$\text{HP.} = \frac{1,950,000}{33,000 \times 2}, \text{ or } \text{HP.} = 29.5.$$

Both the unit horsepower and the unit watt are widely employed in everyday life. The unit horsepower is used to indicate the power developed by such machines as the steam engine and the internal-combustion engine and the power used by such machines as the elevator and crane. The watt is used largely in the field of electricity in connection with the electric motor. One interesting use of the unit horsepower is in the field of aviation, where it is applied not only to the power of the engine but also to the power of the propeller. To find the horsepower exerted by the propeller we use the following equation:

$$\text{HP.} = \frac{\text{thrust in pounds} \times \text{velocity in feet per second}}{550}.$$

ENERGY AND ITS VEHICLE

Power needed for producing forward motion of an airplane wing.

If a forward movement of the wing of an airplane is to be produced, the thrust must be at least equal to the drag. Since power is the rate of doing work and velocity is the rate of motion, we can find the power by multiplying the force by the velocity. If horsepower is desired, the force should be in pounds and the velocity in feet per second. The product of these two will give the work done in one second. Since 550 foot-pounds of work in

a second is one horsepower, then $HP. = \frac{DV}{550}$, where D = the drag and V = the velocity. Since $D = C_D \frac{\rho}{2} SV^2$, this quantity may be substituted in the horsepower formula and we have

$$HP. = \frac{C_D \frac{\rho}{2} SV^3}{550}.$$

Simplifying, $HP. = \frac{C_D \rho SV^3}{2 \times 550}$, where

C_D = the coefficient of the drag.

ρ = number of slugs of air per cubic foot.

Example. How much power is needed for a wing 200 square feet in area when the plane is traveling 120 miles an hour, the coefficient of drag is 0.02 at standard temperature and pressure, and ρ is 0.002378?

Solution. $HP. = \frac{C_D \rho SV^3}{2 \times 550}.$

$$HP. = \frac{0.02 \times 0.002378 \times 200 \times (176)^3}{2 \times 550}.$$

$$HP. = 47.$$

ANSWER THESE QUESTIONS

1. Why is power involved when a man carries a ton of coal up a stairway 10 ft. high, regardless of the time required?
2. What power, if any, is considered when a workman is paid by piece work?
3. If a man is paid for his work by the hour, why is his employer interested in the power which the man employs in his work?

RATE OF DOING WORK

4. If two runners weigh the same but differ in the time required to run 100 yd. under the same conditions, which one has more power?
5. Name two units of power. How are they defined?
6. How can horsepower be translated into watts?

SOLVE THESE PROBLEMS

A

1. How many horsepower are required to raise a two-ton elevator 700 ft. in 2 minutes?
2. How many horsepower has a truck if it exerts a force of 580 lb. and travels 30 mi. per hour?
3. A boy weighing 100 lb. ascends the stairs of an office building to a height of 80 ft. in 40 seconds. At what rate in horsepower is he working?
4. The power of a motor is rated as 100 kilowatts. What is the horsepower of the motor?
5. A windmill pumps 50 gal. of water from a 20-ft. well in 15 minutes. Find its horsepower.
6. Approximately 750 tons of water per minute falls 164 ft. over Niagara Falls. What is the horsepower of the falling water?
7. If a 200-lb. man climbs a stairway and a 100-lb. boy climbs the same stairway in the same length of time, what difference is there in the amounts of power they employ?
8. If a 100-lb. boy climbs a stairway carrying a 10-lb. package and later climbs the same stairway in the same length of time carrying a 50-lb. package, how much more power does he employ on the second trip?

B

9. If a 200-lb. driving force on a 3000-lb. automobile is able to keep the car at a constant speed of 40 mi. per hour, what is the horsepower of the motor?
10. If 500 HP. is used to drive an airplane 200 mi. per hour horizontally, what is the average force exerted by the propeller?
11. If a belt exerts a force of 5 lb. on a pulley that revolves 100 times per minute and is 6 in. in diameter, what horsepower is developed?
12. A water pump raises 600 gal. of water each minute from a well that has its water level 30 ft. below the outlet. If three-fourths of the power delivered to the pump is wasted, what horsepower is required to operate it?



Ewing Galloway

A large quantity of energy is stored up in the powerful arms and shoulders of the man in this picture. As he swings his ax, he employs all this energy to do work for him.

AREA THREE

What Is Meant by Conservation of Energy?

Energy exists in many forms that are familiar in everyday life. A coiled spring, such as used in a clock or watch, and also wood, coal, and other materials that may be burned have the capacity to liberate energy. The energy of the watch spring is conserved when it is released in regular amounts to run the watch. Energy is released in the bonfire when materials are burned. If you cook a picnic dinner over the bonfire, some of the energy is used, but much of it escapes in the form of heat.

Energy is the capacity for doing work. The muscles of the body possess energy because they have the capacity for doing work. They may not do any work, but nevertheless they are able to do it.

CONSERVATION OF ENERGY

The brick on the top of the chimney possesses more energy than the one at the base because the top brick is capable of doing more work. The energy that each brick possesses depends upon the amount of work required to place it in the position it occupies. Each is capable of doing the same amount of work that was required to place it there. This statement is true for all bodies because the amount of energy a body possesses is exactly the same as the useful work required to get it in its condition. The water above the dam, the steam in the engine, the spring of the watch, and the moving automobile all possess the amount of energy that is used in getting them in their conditions, neglecting friction. Since work is required to give a body energy, the units of energy are the same as units of work, namely:

Gravitational units of energy	{ foot-pounds gram-centimeters
Absolute units of energy	{ foot-poundals dyne-centimeters (ergs)

Potential energy. A body possesses potential energy because of its position or condition. The book on the desk possesses potential energy owing to its position. The coiled spring possesses potential energy because its molecules are in a condition that tends to cause the spring to uncoil as shown in Figure 96. Gun-powder possesses potential energy because its molecules are in a

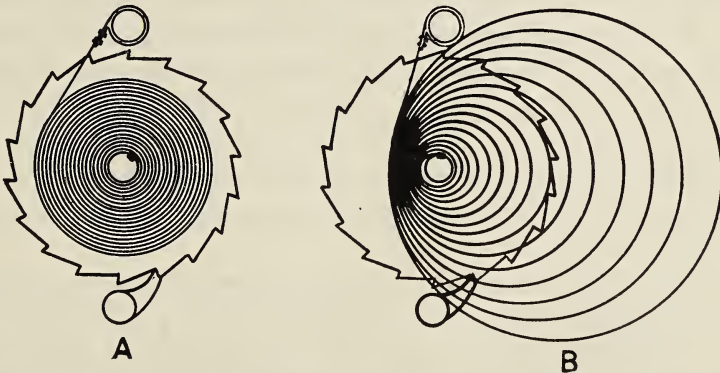


Fig. 96. Potential energy in the coiled spring, A, causes it to uncoil, or unwind, when it is released. The uncoiled spring, B, has spent all its potential energy.

ENERGY AND ITS VEHICLE

condition that causes them to have a tendency to explode. We find the potential energy that a body possesses by calculating the amount of work required to cause the body to possess the energy. $P.E. = FS$, where P.E. stands for potential energy, F stands for force, and S stands for linear space, or distance.

Example. How much energy does a weight of 10 pounds possess if it is 30 feet above the ground?

Solution. The work required to lift the weight this distance is the product of the weight and the distance, therefore, $P.E. = FS = 10 \times 30 = 300$ foot-pounds.

Kinetic energy. A body possesses kinetic energy whenever it is in motion. The kinetic energy that a moving body possesses depends upon the mass of the body and its velocity. If the mass is doubled and the velocity is constant, the kinetic energy is doubled; but if the velocity is doubled and the mass is constant, the kinetic energy is multiplied by 4. If the velocity is trebled and the mass is constant, the kinetic energy is multiplied by 9.

We can determine the number of absolute units of kinetic energy that a moving body possesses by multiplying its mass by the square of its velocity and dividing this product by 2. Stated in a formula, $K.E. = \frac{MV^2}{2}$, where K.E. is the kinetic energy, M is the mass, and V is the velocity of the body. If gravitational units of energy are desired, the absolute units should be divided by the value of gravity, g . The kinetic energy in gravitational units can be found by the formula $K.E. = \frac{MV^2}{2g}$.

Example. How much kinetic energy does an ordinary 2000-pound automobile possess when it travels over an open highway at a rate of 30 miles per hour?

Solution. First we find the velocity in feet per second. Why? 30 miles per hour = 44 feet per second. $K.E. = \frac{1}{2} MV^2 = \frac{1}{2} \times 2000 \times 44^2 = 1,936,000$ foot-pounds. To obtain foot-pounds we divide 1,936,000 foot-pounds by the value of gravity, g , as follows: $1,936,000 \div 32.16 = 60,199.04$ foot-pounds of energy.

CONSERVATION OF ENERGY

Effect of speed in stopping an automobile. Since the kinetic energy of a body is directly proportional to the square of the velocity, an automobile moving 60 miles per hour has four times as much energy as when moving 30 miles per hour. In order to stop it when going 60 miles per hour, the force applied at the brakes must move four times the distance it does to stop when traveling at a rate of 30 miles per hour. This means that the driver of the car must use four times as great a distance in which to stop when traveling at a rate of 60 miles per hour as he does when traveling at a rate of 30 miles per hour. Figure 97 shows the distance in

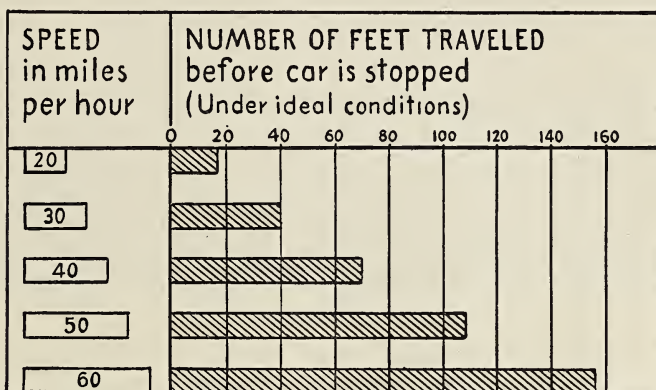


Fig. 97. The bars in the graph indicate the relative distances in feet required to stop a car traveling at each of several speeds.

which the average automobile can be stopped when traveling at different speeds. Every driver of an automobile or any other moving vehicle frequently makes use of this principle of physics. On the basis of this information we should remember that whenever we increase the speed of an automobile we increase by a greater ratio the distance required for stopping.

Energy of a moving bullet. The kinetic-energy formula shows why a bullet fired from a gun has so much more energy than the gun. The momentum of the gun is equal to, but opposite from, the momentum of the bullet. That is, $MV = M_1V_1$ where MV represents the momentum of the gun and M_1V_1 the momentum of

ENERGY AND ITS VEHICLE

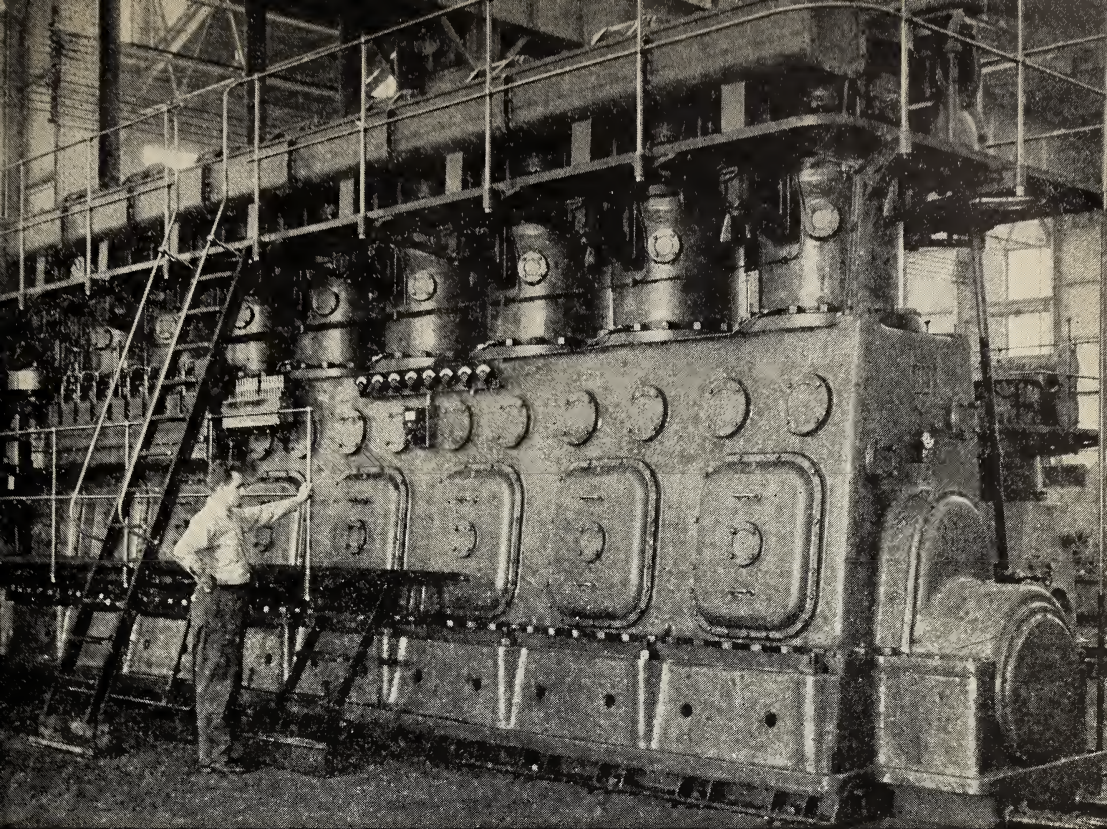
the bullet. The kinetic energy of the gun and the bullet, however, are not equal, as is shown in the following example.

Example. A $\frac{1}{4}$ -ounce bullet is fired with a velocity of 3200 feet per second from an 8-pound rifle. What is the kinetic energy of the bullet and of the rifle?

Solution. $MV = M_1V_1$ or $8V = \frac{1}{64} \times 3200$, $V = 6.25$ feet per second, the kickback velocity of the rifle. The kinetic energy of the rifle is $\text{K.E.} = \frac{1}{2} MV^2 = (8) (6.25)^2 = 156.24$ foot-pounds or $156.24 \div 32.16 = 4.86$ foot-pounds of energy. The kinetic energy of the bullet is $\text{K.E.} = \frac{1}{2} MV^2 = (\frac{1}{2}) (\frac{1}{64}) (3200)^2 = 80,000$ foot-pounds or $80,000 \div 32.16 = 2487.56$ foot-pounds of energy, which is very much greater than that of the rifle.

Conservation of energy. If a bullet is fired vertically from a gun, it possesses kinetic energy when it leaves the gun. As it ascends, its kinetic energy becomes less because gravity causes its velocity to decrease, but its potential energy increases because of its elevated position. When it reaches its maximum height, all its kinetic energy is changed into potential energy. As it descends, its potential energy becomes less and its kinetic energy increases until it reaches the ground, where all the potential energy has changed to kinetic energy. The kinetic energy that it has when it reaches the ground is equal to the kinetic energy that it had when it was fired from the gun, or is equal to the potential energy that it had at its highest elevation, neglecting the factor of air resistance. In this case no energy was lost; neither was there energy gained. One kind of energy is changed into another, but the energy is always present in the same amount. This principle is known as the conservation of energy, which, stated in its most general form, is as follows: *The energy in the universe is always constant; it cannot be created or destroyed but can be transformed.*

Transformation of energy. Energy can readily be transformed from one kind to another. For example, the energy that exists in coal can be changed into heat energy. This heat energy can be changed into mechanical energy by the use of an engine. The



Ferdinand Hirsch

The huge mechanism pictured here is a modern Diesel engine. It is used to generate power for use in a large community. The Diesel engine is capable of transforming a tremendous quantity of heat energy into mechanical energy on an economical basis.

energy of an engine can be changed into electrical energy by the use of an electric generator. The electrical energy can be changed into light energy. In all these transformations energy is neither created nor destroyed. The furnace does not create energy, nor do the engine and electric generator. Each transforms energy from one form to another. In the process of producing energy for use in electric lamps, not all of the energy that the coal possesses is converted into light energy. Some of the energy that is changed into heat energy escapes into space. This energy is not lost, however, when it escapes into the air, for it helps to warm the air and objects in the space near by. Heat energy, mechanical energy, and electrical energy can be transformed or changed into other forms, but they can neither be created nor destroyed.

ENERGY AND ITS VEHICLE

ANSWER THESE QUESTIONS

1. Why is energy measured in the same units as work?
2. Can energy be created? Give an example that illustrates the truth of your answer.
3. How can the transformation of energy be traced from a waterfall to an electric motor?
4. How is energy supplied to the pendulum of a clock?
5. What form of energy does a moving automobile possess? a flying airplane? a moving street car? a running man? a moving steam engine?

SOLVE THESE PROBLEMS

A

1. What is the kinetic energy of a 1-lb. shell if its velocity is 1200 ft. per second?
2. What is the kinetic energy of a 3200-lb. automobile going at the rate of 30 mi. per hour?
3. What is the kinetic energy of the automobile in problem 2 if its speed is 60 mi. per hour?
4. If the same force is used to stop the automobile in problems 2 and 3, how much more space must be allowed to stop it when it is going 60 mi. per hour than when it is going 30 mi. per hour?
5. How much more force is required to stop the automobile in problems 2 and 3 when it is going 30 mi. per hour and 60 mi. per hour, if it is stopped each time in 90 feet?
6. How much kinetic energy has a 180-lb. football player when he is running at the rate of 100 yd. in 12 seconds?
7. How many ergs of energy has a ball weighing 500 g. when it is moving at the rate of 20 meters per second?
8. If the 200-lb. hammer of a pile driver is dropped 64 ft. before it strikes, what is its kinetic energy when it hits?
9. In problem 8 show that the potential energy of the hammer of the pile driver when it is raised 64 ft. is the same as the kinetic energy when it hits.
10. How much potential energy has 1 cu. ft. of water just before it flows over Niagara Falls, which is 164 ft. high?

B

11. Find the kinetic energy in foot-pounds of a 1500-ton train when it travels 40 mi. per hour.

HOW MACHINES AID MAN IN DOING WORK

12. A high diver weighing 160 lb. dives into a lake 100 ft. below the diving board. What is his kinetic energy in foot-pounds the instant he strikes the water?

13. If a baseball pitcher throws a baseball that weighs 9 oz. with a velocity of 120 ft. per second, what is the number of foot-pounds of kinetic energy the ball possesses?

14. Two automobiles each weighing 3000 lb. and each traveling 40 mi. per hour collide "head on." How much kinetic energy in foot-pounds is given up by both cars?

15. A car weighing 3000 lb. traveling 80 mi. per hour strikes a cement wall. How much kinetic energy in foot-pounds is given up?

AREA FOUR

How Do Machines Aid Man in Doing Work?

At some time in our life when we wished to move a heavy object, we may have found the advantage of using a simple machine known as a lever or pry. Many examples may be drawn from everyday life of people using simple machines to help them carry on work. A man uses a jack to lift the axle of an automobile so that he may change a tire. Two men loading a piano on a truck roll the piano up an inclined plane rather than lift the piano straight up. Such illustrations show that simple machines often enable us to do work that we could not do by our hands alone.

Development of large forces. A machine is any device that multiplies force, and hence enables a person to do more work within the same time, or the same work within a shorter time. By means of a bicycle a person can travel farther within the same length of time than he can on foot, even if he runs. A machine also enables a person to take advantage of forces exerted by wind, water, heat, and electricity. By means of the windmill the farmer uses the force of wind to pump water. By means of the water wheel the miller uses the force of falling water to grind grain. By means of the steam engine the engineer uses the force of steam to run machinery. By means of a vacuum cleaner the housewife uses the force of electricity to clean carpets and furniture.

ENERGY AND ITS VEHICLE

If complex machines are examined, they are found to be combinations of simple machines such as levers, inclined planes, pulleys, wheels and axles, and gears. In order to understand complex machines, a study of simple machines is necessary.

The lever, one of the oldest and simplest tools. The lever is merely a rod or pole. Two forces or combinations of forces act on a lever, one the resistance and the other the effort used to overcome the resistance. The advantage of the lever therefore depends upon the distances a small effort and a large resistance are placed from the fulcrum. The small effort is placed a sufficient distance from the fulcrum to provide a moment of force equal to the moment of force produced by the resistance, which is placed relatively close to the fulcrum. Thus the long effort arm in relation to the short resistance arm offsets the small effort in relation to the large resistance. The essential factor is that the moment of force on the effort end of the lever must be equal to that on the resistance end of the lever.

A nutcracker makes use of the principle of the lever. The hinged end of the nutcracker acts as a fulcrum of the lever formed by each of the handles. The nearer the nut, or resistance, is placed to the fulcrum the less effort need be applied.

Ferdinand Hirsh



HOW MACHINES AID MAN IN DOING WORK

Figures 98 and 99 show two types of levers in which a small effort E overcomes a large resistance R . In the first lever the resistance is located between the fulcrum F and the effort E , and in the second lever the fulcrum F is located between the resistance R and the effort E . The distance from the resistance R to the fulcrum F in each drawing, or the resistance arm, is indicated by d_1 , and the distance from the effort E to the fulcrum F in each drawing, or the effort arm, is indicated by d_2 . Under these conditions we find a relationship that always holds true with levers; namely, that the forces E and R are inversely proportional to their distances from the fulcrum, for $E \times d_2 = R \times d_1$, or $E \div R = d_1 \div d_2$.

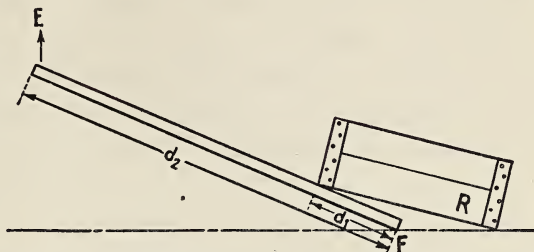


Fig. 98. A small lift may be transformed into a large one through the proper use of the lever principle.

The mechanical advantage of the lever. By the term mechanical advantage we mean the number of times a machine multiplies the effort to overcome the force of resistance. The scientist considers two types of mechanical advantage; namely, actual mechanical advantage and theoretical mechanical advantage. The actual mechanical advantage is the mechanical advantage when friction is taken into account. The theoretical mechanical advantage is the mechanical advantage that would exist if there were no friction. Since there is very little friction in a lever, the actual and theoretical mechanical advantages are practically the same, but in most other machines the difference is greater. If M.A. represents the actual mechanical advantage of a machine, R the resistance to be overcome, and E the effort

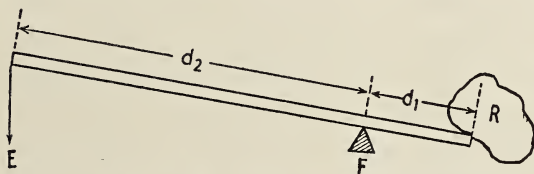


Fig. 99. The principle of the lever will also transform a small push downward into a large lift upward.

ENERGY AND ITS VEHICLE

applied to the machine, we may express the actual mechanical advantage as follows: $M.A. = R \div E$. If T.M.A. represents the theoretical mechanical advantage, we may express the theoretical mechanical advantage as follows: T.M.A. = distance from effort E to fulcrum $\div$ distance from resistance R to fulcrum.

Example. What are the actual and theoretical mechanical advantages of a lever used in prying a log at a sawmill when a force of 50 pounds is applied 10 feet from the fulcrum to overcome a resistance of 500 pounds 0.9 feet from the fulcrum?

Solution. Substituting in the first of the foregoing equations, namely, $M.A. = R \div E$, we obtain $M.A. = 500 \div 50$, or $M.A. = 10$. Substituting in the second equation, namely, T.M.A. = distance from E to fulcrum $\div$ distance from R to fulcrum, we obtain T.M.A. = $10 \div 0.9$, or T.M.A. = 11.11.

Ice tongs and scissors are examples of levers with the fulcrum located between the resistance and the effort. The wheelbarrow is an example of a lever with the resistance located between the fulcrum and the effort, the axle of the wheel serving as a fulcrum. The human arm is an example of a lever with the effort located between the fulcrum and the resistance.

Velocity ratio. Besides being used to gain force a lever may also be used to gain speed. In such a case the effort is applied relatively close to the fulcrum and the resistance some distance away. Under this arrangement the resistance moves through a greater distance than when the effort is applied to gain force. Whenever the mechanical advantage is less than one, the resistance moves faster than the effort. The ratio of the velocity of the effort to the velocity of the resistance is known as the velocity ratio expressed in the form of an equation as follows:

$$\text{Velocity ratio} = \frac{\text{velocity of effort}}{\text{velocity of resistance}}.$$

Example. A 10-pound resistance is supported on a lever 6 feet from the fulcrum of the lever by a 20-pound effort 3 feet from the fulcrum. What is the theoretical mechanical advantage of the lever and what is the velocity ratio?

HOW MACHINES AID MAN IN DOING WORK

Solution. According to the equation for finding the theoretical mechanical advantage, the T.M.A. = $3 \div 6$, or 0.5. According to the foregoing equation, the velocity ratio = $3 \div 6$, or 0.5. Therefore the theoretical mechanical advantage, as we can readily see, is numerically the same as the velocity ratio.

ANSWER THESE QUESTIONS

1. Locate the effort, resistance, and fulcrum in the levers illustrated in Figure 100. Is the theoretical mechanical advantage more or less than one in each lever?

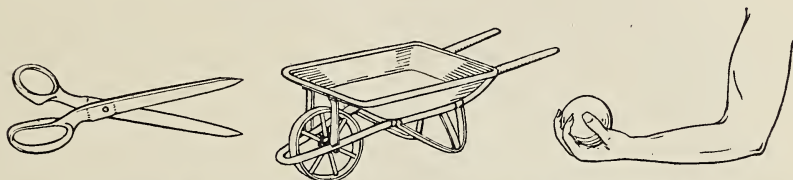


Fig. 100. Three simple applications of the principle of the lever common in everyday life.

2. What is a machine?
3. What levers are found in the automobile?
4. When does a lever have a large mechanical advantage?
5. Give three different relative positions that the effort, the resistance, and the fulcrum may occupy. Which position will always give a theoretical mechanical advantage of less than one?
6. Why is the theoretical mechanical advantage always more than the actual mechanical advantage?
7. What is the velocity ratio?
8. When velocity is gained, what is sacrificed?
9. What are some machines in which velocity is gained?

SOLVE THESE PROBLEMS

A

1. A sack of corn hung 15 in. from the fulcrum of a lever is balanced by a 50-lb. weight hung 18 in. from the fulcrum. What is the weight of the corn, if the weight of the lever is neglected?
2. Two boys balance each other on a seesaw 14 ft. long. One boy weighs 120 lb. and sits 6 ft. from the fulcrum, which is at the center of gravity of the seesaw, and the second boy sits 5 ft. from the fulcrum. How much does the second boy weigh?

ENERGY AND ITS VEHICLE

3. Neglecting the weight of the plank, where should the fulcrum be placed if each of the boys in problem 2 sits 1 ft. from his end of the plank?

4. Two boys hold the ends of a bar 4 ft. long and carry a load weighing 180 lb. suspended from the bar. One boy can carry 100 lb. and the other 80 lb. Where should the load be suspended from the bar if the weight of the bar is neglected?

5. The center of gravity of a plank is 2 ft. from the fulcrum. When a weight of 20 lb. is suspended from the plank 3 ft. from the fulcrum, the plank is balanced. What is the weight of the plank?

B

6. A bridge 200 ft. long weighs 90 tons. An engine that weighs 50 tons crosses the bridge. What is the load on each pier when the engine is 80 ft. from one end? when the engine is at the center?

7. A steel rail 10 ft. long weighs 500 pounds. It is carried by three men located as follows: one of the men is at one end and the other two help to carry the load by means of a bar located 2 ft. from the other end. How many pounds does each man carry?

8. Two horses draw a wagon that requires 500 lb. of force to move it. Each horse is hitched to singletrees attached at each end of the doubletree. Where must the doubletree, which is 4 ft. long, be attached to the wagon so that one horse will pull 300 lb. and the other horse pull 200 pounds?

9. A "pop-off" valve 4 in. in diameter and weighing 50 lb. is attached to a lever 4 in. from the fastened end. The lever, which is 40 in. long and weighs 40 lb., has its center of gravity 12 in. from the fastened end. Where must a 200-lb. weight be hung so that the steam will "blow off" at 150 lb. per square inch?

AREA FIVE

How Are the Mechanical Advantages of Different Machines Measured?

One of the important inventions in the long history of mankind is the wheel and axle. Before its invention loads had to be floated on streams, carried on the backs of men or beasts, or dragged. Consequently the invention of this simple machine added greatly to man's capacity for doing work. Likewise the invention of such



The student in this picture is measuring the outside diameter of the wheel on a laboratory model of the wheel and axle. By comparing this with the smaller diameter from which the lower weight is suspended, he can calculate the mechanical advantage.

simple machines as the inclined plane and the pulley added to his capacity for doing work. In this area we shall study the principles underlying the work of various simple machines.

The wheel and axle. The wheel and axle consists of a wheel fastened rigidly to an axle so that both turn around the same axis. Sometimes a crank rather than a wheel is attached to the axle, but the principle of operation is the same. The effort is applied at a point on the circumference of the wheel, and the machine operates upon somewhat the same principle as the lever. On this basis the effort is the force applied, the radius of the wheel is the effort arm, the radius of the axle is the resistance arm, and the common center is the fulcrum. If R represents the effort arm or the radius of the wheel, then $2\pi R$ represents the distance through

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which the effort moves in one revolution. If r represents the resistance arm of the radius of the axle, then $2\pi r$ represents the distance through which the resistance moves in one revolution. The theoretical mechanical advantage, or the T.M.A., as we have learned, equals the effort distance divided by the resistance distance. Applying this relationship to the wheel and axle, we obtain

$$\text{T.M.A.} = \frac{2\pi R}{2\pi r}, \text{ or } \text{T.M.A.} = \frac{R}{r}.$$

Example. What is the theoretical mechanical advantage of a wheel and axle when the radius of the wheel is 10 inches and the radius of the axle is 2 inches?

Solution. Substituting 10 for R and 2 for r in the above equation, we obtain $\text{T.M.A.} = 10 \div 2 = 5$.

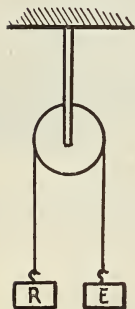


Fig. 101. A single pulley of the fixed type.

The pulley. A pulley is a wheel with a grooved rim that turns on an axis in a frame or block. Such a wheel is used in lifting weights, the effort being applied at one end of a rope or cable and the resistance at the other. When a pulley is fastened to a fixed support, as shown in Figure 101, the pulley is known as a fixed pulley. The theoretical mechanical advantage of a fixed pulley is one, because effort E moves through the same distance as resistance R . For what purposes is this fixed pulley used?

When a pulley is raised or lowered by means of a rope or cable passing around the grooved rim of the pulley, the pulley is known as a movable pulley. If such a pulley is suspended, as shown in Figure 102, and resistance R is applied to the movable pulley and effort E at the free end of the rope, the theoretical mechanical advantage is two because E moves twice as far as R . The force of the resistance is divided equally between the two strands of the rope supporting the pulley. The movable pulley is widely used in factories and machine shops for lifting loads too heavy to be lifted by hand.

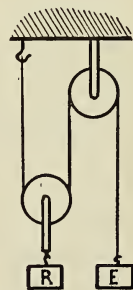


Fig. 102. Two pulleys, movable and fixed.

MECHANICAL ADVANTAGES OF MACHINES

A system of pulleys. Frequently two fixed and two movable pulleys are arranged in a system known as a block and tackle, as shown in Figure 103. The theoretical mechanical advantage of such a system is four because the effort moves four times as far as the resistance. The force of the resistance is divided equally among four strands of rope.

The theoretical mechanical advantage of a system of pulleys is always the same as the number of supporting strands. The actual mechanical advantage, however, is less than the theoretical mechanical advantage because some of the force is used in overcoming friction and the weight of the movable block. Of course, we find the actual mechanical advantage by dividing the resistance by the effort.

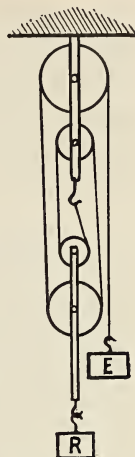


Fig. 103. A system of pulleys.

The differential pulley. The differential pulley, as shown in Figure 104, is a combination of the wheel and axle and the movable-type pulley. The upper part of the system consists of a wheel and axle fastened together and rotating about the same axis. The radius of the wheel is designated by r and the radius of the axle by r' . The lower part of the system is a single movable pulley supported by an endless chain that extends around both the upper pulley and the axis. The rims of the pulleys and axis have cogs to prevent the chain from slipping.

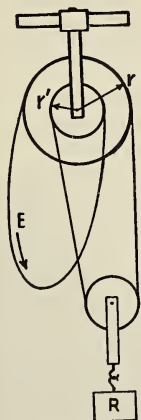


Fig. 104. Differential pulley.

The effort E is applied to the differential pulley along the chain as indicated by the arrow and the resistance is attached to the movable pulley. Thus winding the wheel of the upper part lifts resistance R , but the axle turning at the same time lowers resistance R . When the wheel makes one complete revolution it winds up $2\pi r$ of the chain. When the axle makes one complete revolution it winds up $2\pi r'$ of the chain. Earlier we found, however, that when a movable pulley is supported by two strands,

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the resistance moves only one-half as far as the effort. If we apply this rule to the differential pulley we find that when the effort E moves $2\pi r$, the resistance R moves one-half the difference between $2\pi r$ and $2\pi r'$, or $\frac{1}{2}(2\pi r - 2\pi r')$. On the basis of these findings we may calculate the theoretical mechanical advantage as follows:

$$\text{T.M.A.} = \frac{\text{distance effort moves}}{\text{distance resistance moves}} = \frac{2\pi r}{\frac{1}{2}(2\pi r - 2\pi r')} = \frac{2r}{r - r'}$$

We may also calculate the theoretical mechanical advantage of the differential pulley by letting r and r' represent the number of cogs on the wheel and axle respectively. In such a case we merely substitute the number of cogs in the foregoing equation. Thus if the wheel has 10 cogs and the axle has 5 cogs we find the theoretical mechanical advantage as follows:

$$\text{T.M.A.} = \frac{2 \times 10}{10 - 5} = 4.$$

The inclined plane. An inclined plane is a machine that has its surface inclined at an angle with the horizontal. Examples of inclined planes are a hill, a stairway, and a board reaching from the ground to the bed of a truck. The inclined plane is used to lift or roll heavy objects from one level to another. For instance, it is impossible for two men to lift a heavy piano from the ground onto a truck, but it is comparatively easy to slide it up an inclined

The gradual slopes and curves along this picturesque highway enhance the pleasures of automobile travel. They also represent an application of the principle of the inclined plane. Travel is much more difficult when the slopes are steep and straight.

Ewing Galloway



MECHANICAL ADVANTAGES OF MACHINES

plane. It is impossible to reach the top of a steep mountain by driving an automobile directly up the steep slope of the mountain, but winding roads with gradual slopes make the ascent easy. It is difficult for a person to climb vertically from the first floor to the second floor of a house, but he may walk up a series of steps with ease.

The effort required to move an object up an inclined plane varies with the angle between the plane and the horizontal. The greater the angle the greater is the effort required, and the less the angle the less is the effort required. For instance, if angle ACB , in Figure 105, is increased, a greater effort is required to move resistance R up the incline. The actual mechanical advan-

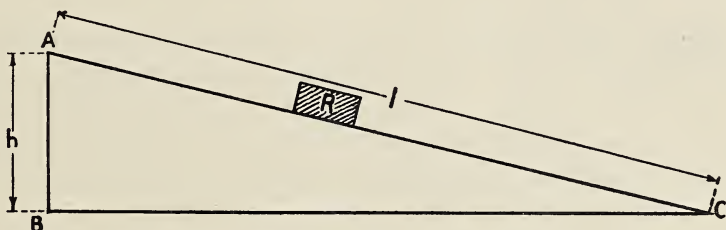


Fig. 105. Diagram showing the factors involved in pulling a weight up an inclined plane. The effort required depends upon the size of the angle at C .

tage of an inclined plane is the resistance R divided by the effort E applied to overcome the resistance, or $M.A. = R \div E$. The theoretical mechanical advantage, on the other hand, is the length of the plane l divided by the height of the plane h , or $T.M.A. = l \div h$. On the basis of these equations, if we neglect friction, we may say that the resistance divided by the effort equals the length of the inclined plane divided by the height, or $R \div E = l \div h$.

Example. If friction is neglected, how much effort is required to push an object weighing 2000 pounds up an inclined plane 20 feet long and 4 feet high?

Solution. To solve this problem we substitute in the last equation given above as follows:

$$2000 \div E = 20 \div 4, \text{ or } E = 400 \text{ pounds.}$$

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The grade of a hill. Highway engineers frequently speak of the grade of a hill. By grade they mean the relation of the vertical rise to the horizontal distance expressed in percentage.



Fig. 106. The necessary pull of the engine of the car depends upon the percentage of grade of the hill.

For example, if h represents the vertical distance of the grade shown in Figure 106 and d the horizontal distance, the grade is $h \div d$. If d is 100 feet and h is 2 feet, the

grade is $2 \div 100$, or 2 per cent. Most railroad grades are less than 2 per cent, but highway grades are often 12 per cent.

The wedge. Another form of inclined plane is the wedge. A wedge consists of two plane surfaces set in the shape of the letter **V**. The wedge is widely used in splitting objects such as logs. Frequently the wedge is attached to a handle and used as a tool for splitting or cutting as with a hatchet or an ax.

The screw. Still another form of the inclined plane is the screw, which consists of a cone with a spiral groove extending along the circumference, as shown at the left in Figure 107. The distance between two adjoining threads, represented by d in the drawing at the right, is known as the pitch. When a twisting force is applied at the top, the screw moves forward because of the pitch, one revolution of the force causing it to move forward the same distance as the pitch. If the force is applied at the end of a lever, as in the case of a jackscrew, the force moves through a distance of $2\pi r$. The theoretical mechanical advantage of the screw may be determined in the same manner as that of the inclined plane, namely, by dividing the distance through which the force moves by

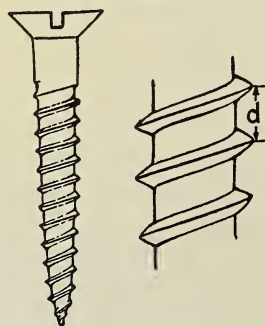


Fig. 107. A simple screw showing the threads and pitches.

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the distance through which the resistance moves. If $2\pi r$ represents the distance through which the force moves and d (the pitch of the screw) the distance through which the resistance moves, the procedure may be expressed by the following equation: $T.M.A. = \frac{2\pi r}{d}$.

Train of gear wheels. The train of gear wheels is an application of the wheel and axle that was described on page 269. It is really a series of wheels and axles connected to form a single mechanical unit. Figure 108 illustrates the working parts of the train of gear wheels. When gear 3 makes one complete turn, gear 2 makes only part of a turn, and gear 1 makes even less of a turn. The mechanical advantage of this arrangement is easily computed when we know the measurements of the several parts. Suppose the force F is attached to the circum-

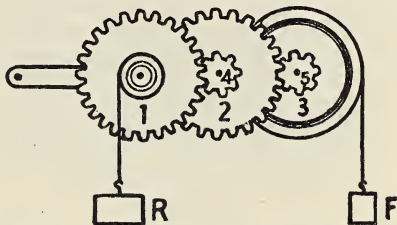


Fig. 108. A train of gear wheels is used to multiply force mechanically.

ference of the axle of gear 3. The teeth of gear 1, which is called the pinion, mesh into the teeth of gear 4. The teeth of gear 2 mesh into the teeth of gear 5. Suppose gears 1 and 2 have 48 teeth each, and gears 4 and 5 have 12 teeth each, and the radius of the axle of gear 1 is 2 inches, while the radius of gear 3 is 12 inches. When gear 1 makes a complete revolution, gear 2 makes $48 \div 12$ or 4 revolutions. When gear 2 makes one complete revolution, gear 3 makes $48 \div 12$ or 4 revolutions. Therefore, when gear 1 makes one complete revolution, gear 3 makes 4×4 or 16 revolutions. Since the force is applied on the circumference of gear 3 and the resistance on the axle of gear 1, the theoretical mechanical advantage because of the teeth is 16. Since the diameter of gear 3 is 12 inches and the diameter of the axle of gear 1 is 2 inches, the theoretical mechanical advantage because of the diameters is $12 \div 2$ or 6. Therefore, the total T.M.A. of the train of gears is $4 \times 4 \times 6$ or 96.

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Automobile transmission. The automobile transmission is an example of a train of gears used to transfer energy. A typical set of automobile gears is shown in Figure 109. The explosions of the gas in the cylinders cause the crankshaft to turn. Attached to the crankshaft through the clutch is gear 1, which is always meshed with gear 8. Gear 8 and all others on the countershaft are rigidly attached to the countershaft. Since gear 1 has fewer teeth than gear 8, the countershaft does not turn so fast as the

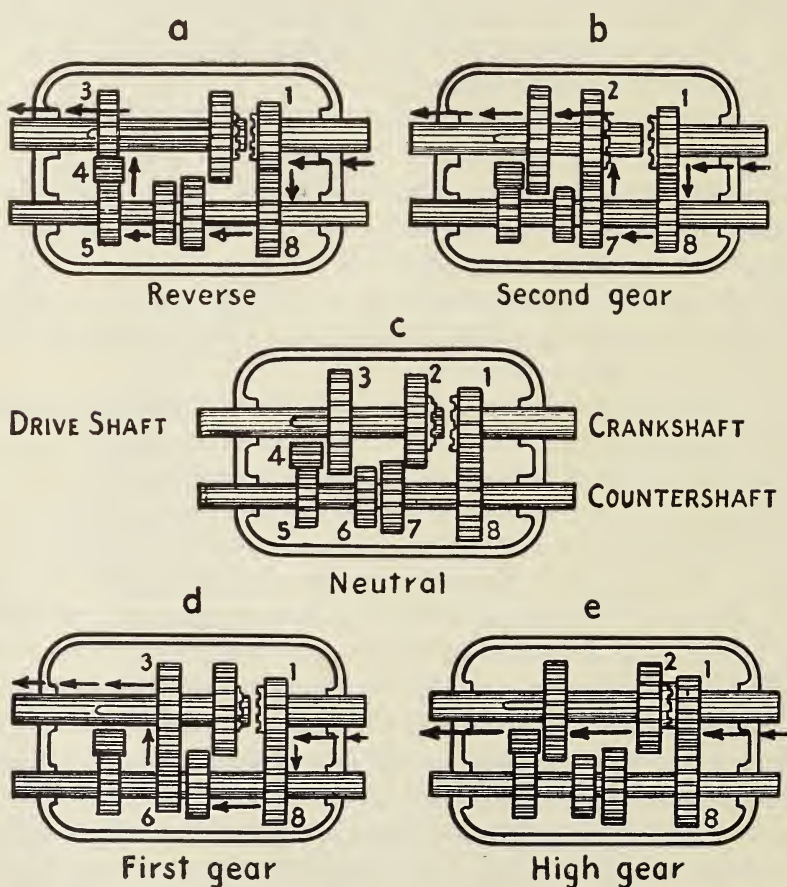


Fig. 109. The above diagram shows the essential parts of an automobile transmission, or the system of gears used in transmitting power from the engine to the drive shaft.

MECHANICAL ADVANTAGES OF MACHINES

crankshaft. If these are the only gears meshed, the transmission is in neutral. Gears 2 and 3 can be made to slide along the drive shaft by the use of a shifting lever controlled either by the driver or automatically. When gear 3 is shifted so that it meshes with gear 6, the power travels as indicated in the figure. Gear 6 has fewer teeth than gear 3; therefore the speed of the crankshaft is again reduced before it reaches the drive shaft. If gear 2 is shifted to gear 7, the power then follows the path indicated in the figure. In high speed the crankshaft engages the drive shaft. Gear 1 is still engaged in gear 8, causing the countershaft to run; but since none of the other countershaft gears are engaged, the power goes directly from the crankshaft to the drive shaft. Gear 4, which is called the idler, is on another countershaft and meshes with gear 5. When gear 3 is shifted so that it meshes with gear 4 and gear 4 meshes with gear 5, the machine is in reverse. Gear 4 causes this reverse, but it does not change the gear ratio between gears 3 and 5.

Clutchless automobiles. In some makes of automobiles the coupling of the engine to the transmission is done by means of a liquid by the turbine principle. The liquid-coupling principle can be illustrated by two electric fans so placed that they face each other a few inches apart. One fan is connected to electric power, while the other fan is free to turn but has no electrical connection. As the power-driven fan increases its speed, an impulse of power is transmitted through the air so that the other fan begins to turn. It will gradually gain speed until it revolves almost as fast as the power-driven fan. If it were possible to place the two fans under water, the same action would take place. The liquid coupling of the engine to the transmission works upon the same principle as the fans except that oil is used as the medium of power transmission instead of air.

The liquid coupling is a closed-circuit turbine. It consists of, first, a primary shaft upon which is fastened an impeller driven by the engine. This impeller corresponds to the power-driven electric fan as described above. The second member of the

ENERGY AND ITS VEHICLE

coupling is a secondary shaft upon which is fastened a runner. The runner corresponds to the fan not connected to electric power as described above. The whole mechanism runs in oil. As the engine turns the impeller, its power is transmitted through the oil to the runner that carries it to the transmission and on to the wheels. In some automobiles the gears of the transmission are automatically shifted as the speed of the engine changes.

The differential. After passing through the transmission, the power from the engine is carried by the drive shaft on its way to the rear wheels. An elaborate mechanism is necessary between the drive shaft and the rear axles in order to furnish both rear wheels with equal amounts of power and yet allow them to turn at different speeds, as they must do when the car is moving around a curve. This mechanism is called the differential.

Figure 110 shows how the differential operates. The rear end of the drive shaft is a gear *A* that meshes with the bevel gear *B*. The frame *K* is rigidly attached to *B* and, therefore, turns with it. The axles *C* and *D* pass through the bevel gear and frame as shown but are not attached to them, and end in gears *E* and *F*. Gears *G* and *H*, called differential gears, mesh with *E* and *F* and may if necessary turn freely on their shafts, which are

attached to the frame. As the drive shaft turns, the bevel gear *B*, the frame *K*, and the differential gears *G* and *H* also turn, thus forcing the axle gears *E* and *F* to turn also. The power is thus furnished to the wheels, which are attached rigidly to the outer ends of the axles. If the car is going in a straight line, the differential gears do not rotate on their own shafts but merely revolve with *K*. On a curve, however, when one axle must rotate faster than the other, *G* and *H* will rotate on their own shafts but in

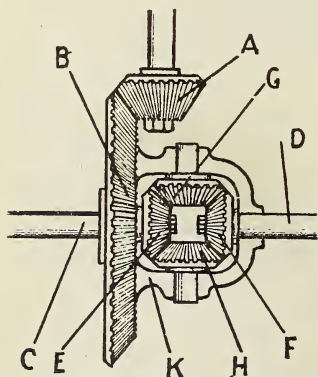


Fig. 110. Diagram showing the essential parts of a differential, which is a series of beveled gears.

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opposite directions as they continue to revolve with K . One wheel may even stop turning altogether as the other continues to turn. A common example of this situation is an automobile with one wheel spinning freely in a mud hole while the other is resting on the road without turning.

The worm gear. The worm gear, which is often used in the rear drive of an auto truck, is a combination of the lever, screw, and toothed wheels. Its mechanical advantage is generally large. A screw is placed upon a shaft turned by means of a lever L , as shown in Figure 111. It is tangent to the cogwheel C , which revolves under the housing H . The effort E is applied at the end of the lever L , and the resistance is applied on the circumference of the axle A of the cogwheel. When the screw makes one complete turn, the cogwheel rotates the distance between two successive cogs. Suppose the number of cogs N is 50, the lever arm L is 4 inches long, and the radius r of the axle is one inch long. When the effort E makes one rotation, it travels $2\pi L$ inches while the axle to which the resistance is attached, turns $\frac{2\pi r}{N}$ inches. Since

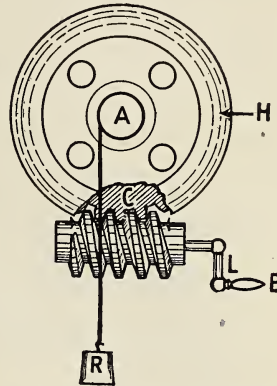
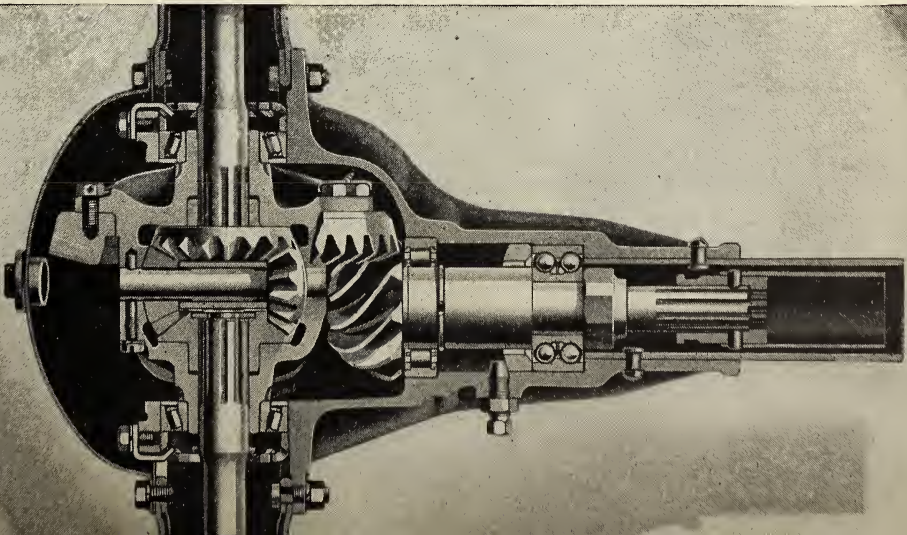


Fig. 111. Drawing of a worm gear showing essential parts.

This picture shows a cross section of the differential of an automobile. This complicated mechanism consists of a series of beveled gears which multiply the force exerted upon the drive shaft and distribute it to the rear wheels of the automobile.

Ferdinand Hirsch



ENERGY AND ITS VEHICLE

we find the theoretical mechanical advantage of a machine by dividing the distance the effort travels by the distance the resistance travels, the theoretical mechanical advantage of this

$$\text{worm gear is } \frac{\frac{2\pi L}{2\pi r}}{N} = \frac{NL}{r} \text{ or } \frac{50 \times 4}{1} = 200.$$

ANSWER THESE QUESTIONS

1. What conditions are necessary in a wheel and axle with a theoretical mechanical advantage of 5?
2. What machines use the principle of the wheel and axle?
3. How can you readily tell the theoretical mechanical advantage of a system of pulleys?
4. What conditions are necessary in a system of pulleys with a theoretical mechanical advantage of 7?
5. Why are stairways a modification of an inclined plane?
6. Upon what does the mechanical advantage of a differential pulley depend?
7. What is meant by a gear ratio?
8. What conditions are necessary for a train of gears with a gear ratio of 48 to 1?
9. Is the gear ratio more when an automobile is in high or when it is in low?
10. How is the mechanical advantage of a compound machine found?
11. Upon what does the theoretical mechanical advantage of an inclined plane depend?
12. Why are reduction gears generally employed when an electric motor is used to run a machine?
13. Why do bicycles have a large sprocket wheel attached to the pedals and a small sprocket wheel attached to the rear wheel?
14. In a mountainous country would the gear ratio of an automobile be higher or lower than on a plain?

SOLVE THESE PROBLEMS

A

1. If the handle of a windlass is 2 ft. long and the axle is 6 in. in diameter, what is the theoretical mechanical advantage?
2. If a system of pulleys has five supporting strands, what is the theoretical mechanical advantage?

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3. If the lever arm of a jackscrew is 2.5 ft. and the threads are $\frac{1}{2}$ in. apart, what is the theoretical mechanical advantage?
4. If the length of an inclined plane is 20 ft. and one end rests upon the ground while the other rests upon a truck 3 ft. high, what is the theoretical mechanical advantage?
5. If the radii of the wheels of a differential pulley are 10 and 8 in. respectively, what is the theoretical mechanical advantage?
6. If the front sprocket of a bicycle has 72 cogs and the rear sprocket has 12 cogs, how many times will the rear wheel go around when the pedals go around once?

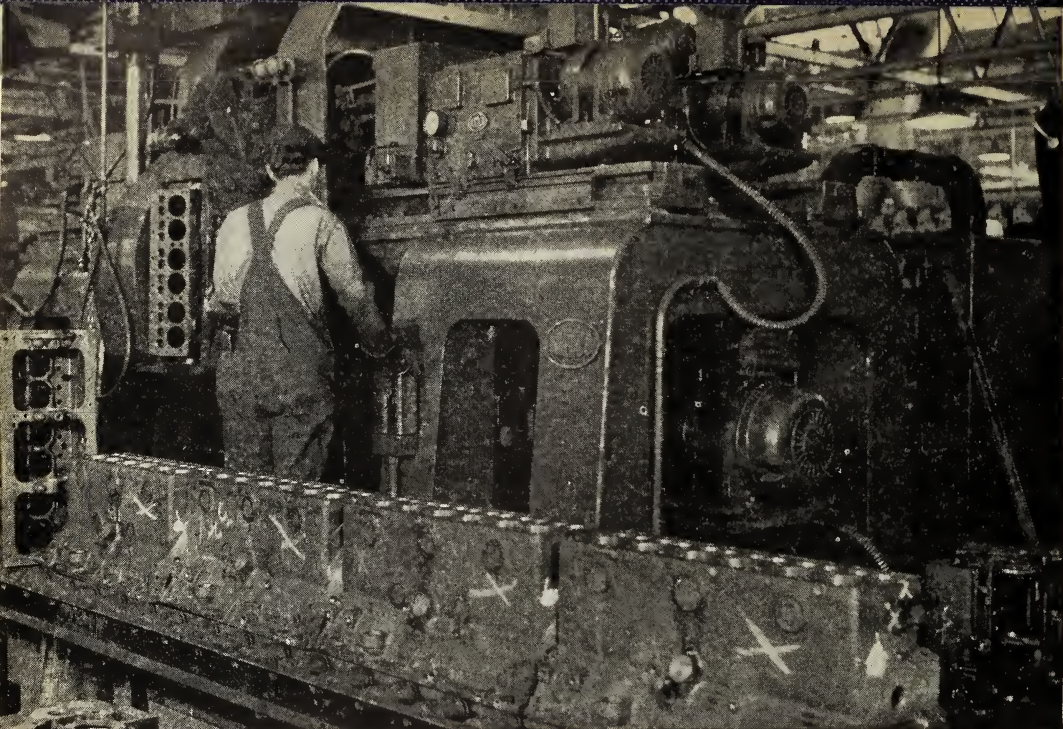
B

7. A windlass has a crank handle 40 in. long and an axle 4 in. in diameter. What is the theoretical mechanical advantage? What is the actual mechanical advantage if, on account of friction, the force applied is 30 per cent larger than if there were no friction?
8. A system of pulleys with four strands has applied to it a force of 100 pounds. What load will it lift if 20 per cent of the applied force is used to overcome friction?
9. A jackscrew has five single threads to the inch. The lever arm is 30 in. long. If 50 per cent of the applied force is used to overcome friction, how large a load can be lifted with a force of 80 pounds?
10. A 300-lb. block of ice is pulled up an inclined plane with a force parallel to the plane. If the plane is 10 ft. long and 3 ft. high, what force is required if friction is neglected?
11. In a differential pulley the radii of the upper wheels are 6 in. and $5\frac{1}{4}$ in. respectively. If 40 per cent of the force is used to overcome friction, what load can be lifted with a force of 60 pounds?

AREA SIX

How Is Friction Controlled?

Whenever you move your hand over the surface of a piece of lumber, cloth, or paper, you feel that it is more or less rough. There is a tendency for your hand to be held back, and more effort is required to move it over a rough surface than over a smooth surface. This resistance of one surface to another is called friction. When two rough surfaces such as two bricks are moved over each other, the friction is fully evident. Even when two surfaces that



Century Photos, Inc.

The huge piece of machinery shown here turns out automobile cylinder blocks. As the parts of the machine operate, they are constantly creating and overcoming friction. It is difficult to visualize the universal influence of friction upon all machines.

seem very smooth pass over each other a little friction is produced, even though it may be hard to detect. The friction in machines cannot be ignored because extra force is always required to overcome its resistance.

What is the nature of friction? Friction may be defined as the resistance that a body encounters when it slides or rolls over the surface of another object. The resistance occurs because projections in the surface of the one object fit into depressions

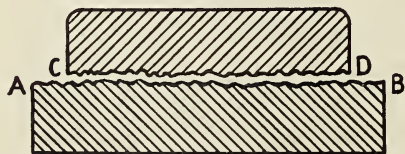


Fig. 112. Surfaces CD and AB are magnified to show how surface resistance occurs.

in the surface of the other object as shown in Figure 112. The greater the pressure between the objects and the rougher the contacting surfaces, of course, the greater is the resistance. To overcome the effect of friction

machinists commonly apply oil or grease to the contacting surfaces. The oil lessens the resistance because it enables the projections to slide out of the depressions more easily and thus to have less effect on the motion.

Movement involves friction. Whenever two solids are moved over each other, as when a book is moved over the surface of a desk, friction occurs. It occurs between a solid and a liquid when a boat moves through the water. It occurs between a solid and a gas when an airplane moves through the air. It also occurs between a liquid and a gas when water falls through air. In short, all movements of solids, liquids, and gases involve friction.

Although the reduction of friction is desirable in many cases, its increase is desirable in many others. For example, the clutch of an automobile works only because there is much friction between the two surfaces. A belt drives a pulley because friction exists between the belt and the pulley. Chains are placed upon the wheels of an automobile to increase friction between the icy road and the wheels. If it were not for friction one would be unable to walk.

An automobile clutch. When an automobile is started, the engine must first be accelerated to a relatively high speed to develop enough power. While the engine is being accelerated, it must be disconnected from the system that transfers the power to the driving shaft. To connect the power transmission system to the engine and to disconnect it, the clutch is used.

The clutch is a friction device that transfers the power from the crankshaft to the transmission shaft. Attached to the crankshaft is a flywheel which rotates with the crankshaft and is provided with a circular friction plate. Facing the plate is another friction plate connected indirectly with the crankshaft. In using the clutch a driver lets out the clutch lever slowly to permit the circular friction plate to come into contact with the circular friction plate attached to the flywheel. This action permits both parts of the system gradually to acquire the same speed.

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Factors influencing frictional force. Whenever friction occurs between two objects, one sliding over the other, several factors determine the amount of the frictional force. We can understand

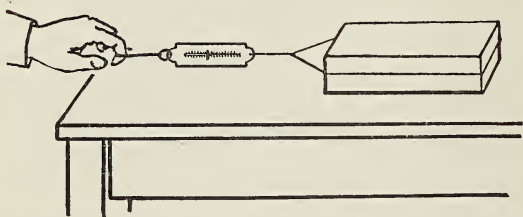


Fig. 113. You can measure friction by measuring the force of the pull required to overcome it.

these factors by means of several simple experiments with a brick and a spring balance placed on a table with a wooden top, as shown in Figure 113. (1) We place a small brick weighing 5 pounds upon the table and

note the pull upon the spring balance, and then place a larger brick weighing 10 pounds upon the table and note the pull. The reading in the first case is one-half that in the second, from which we may conclude that sliding friction is directly proportional to the normal or perpendicular force acting between the two surfaces. (2) We place a brick flat upon the table and note the pull upon the spring balance, and then place the brick upon its edge and note the pull. The reading is the same in both cases, and therefore we may conclude that sliding friction is independent of the area of the surfaces. (3) We slide the brick slowly and then more rapidly and observe the pull upon the spring balance. The reading decreases with the speed of the brick, and therefore we may conclude that sliding friction decreases with very high speed. (4) Finally we slide the brick, first upon a table with a wooden top, then upon a table with a glass top, and note the pull upon the spring balance. The reading is greater in the first instance than in the second, and therefore we may conclude that sliding friction depends upon the kinds of surfaces.

Coefficient of friction. Engineers, in designing machines, are concerned with a ratio known as the coefficient of friction. This ratio represents the relation between the force necessary to cause one object to slide or roll over another object and the perpendicular

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force of gravity (frequently called the natural force) that presses the objects together. For instance, if we attach a spring balance to a brick lying on a table and pull the spring balance to move the brick, the coefficient of friction is the force expressed in pounds on the scale divided by the weight of the brick expressed in pounds. The coefficient of friction may be expressed as:

$$\text{C. F.} = \frac{\text{force parallel to surface}}{\text{force perpendicular to surface due to weight}}$$

The coefficient of friction differs with different materials because the rubbing surfaces vary with the nature of the materials. The coefficient of friction between two pieces of smooth dry oak, for instance, is 0.5; between a piece of iron and a piece of dry leather it is 0.55; and between a piece of iron and oily leather it is 0.15. Such ratios, of course, must be taken into account in using the equation given above.

Example. How much force parallel to the surface is required to pull a 500-pound block of dry oak over a similar block of dry oak if the coefficient of friction is 0.5?

Solution. To solve this problem we substitute 0.5 for the coefficient of friction and 500 for the perpendicular force as follows:

$$0.5 = \frac{\text{force parallel to surface}}{500}, \text{ or parallel force} = 250 \text{ pounds.}$$

Frequently we use a method called the inclined-plane method to find the coefficient of friction. Suppose we adjust the inclined plane shown in Figure 114 so that the component of gravity is barely enough to cause the object to slide downward without acceleration. With such an adjustment, the angle between the slope and the horizontal is known as the angle of repose. The horizontal distance of the inclined plane

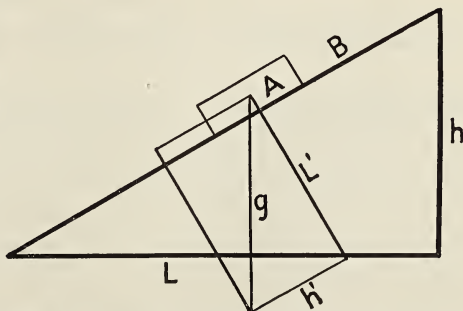


Fig. 114. Diagram showing the factors involved in computing the coefficient of friction.

ENERGY AND ITS VEHICLE

in the drawing is L and the height of the plane is h . The force of gravity, represented by line g , consists of two components represented by lines L' and h' . The first component L' represents the force that causes object A to exert pressure and hence to cause friction. The second component h' represents the component that causes object A to slide slowly down the plane. The right triangle formed with g as a hypotenuse, however, is similar to the right triangle formed by a cross section of the inclined plane. Consequently, $h' \div L' = h \div L$. Since $h \div L$ has the same relation as $h' \div L'$ and the latter represents the relation between the force parallel to the plane which overcomes friction and the force perpendicular to the plane representing gravity, the coefficient may be found by dividing h by L .

Rolling friction. If we have ever tried to ride a bicycle in loose sand we may have noticed that the wheels cut grooves in the sand and produced the same effect as if we were constantly riding uphill. This is what happens when a rolling object moves over a surface, as shown in Figure 115. When an automobile goes over a cement road, the friction of the tires upon the road has two

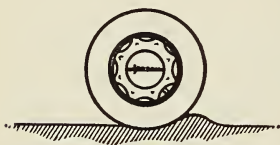


Fig. 115. An object rolling on a surface causes friction.

causes: (1) The weight of the machine causes a very small depression in the road, and, like the bicycle in the sand, it is constantly getting out of the depression and climbing up a very slight elevation. (2) The continual flattening-out of the automobile tires hinders motion, thus causing friction.

Reduction of friction. Friction causes heat. The elimination of as much friction as possible is desirable to avoid overheating when two surfaces in a machine slide over each other. We may reduce friction by first getting the surfaces as smooth as possible and then having them run in a lubricating oil or grease. The oil or grease covers both sliding surfaces and reduces the friction because the coefficient of friction between two fluid surfaces is much less than between two solid surfaces. Another means of



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This is not a picture of an actual street-corner scene. It is a picture of a practice driving range that has been constructed for use in teaching safe driving habits. The realistic traffic lights and crossings help to develop alertness in driving.

reducing friction is to use rolling surfaces instead of sliding surfaces, such as cone, roller, and ball bearings. The bearings also run in lubricating oil or grease.

Drive safely. The modern automobile is an intricate combination of machines, very skillfully designed and carefully manufactured. When delivered to the buyer, it has a powerful motor, well-adjusted brakes, and good tires. It will accelerate quickly, go fast, and steer easily. Most drivers are sure they are good drivers and pride themselves on their control over the movements of their cars. In reality, no driver controls his car. The only control over the movement of any car is the force of friction between the tires and the pavement. Mistakes in estimating the amount of

ENERGY AND ITS VEHICLE

frictional force available for stopping the car or keeping it from skidding cause a great many accidents. A little ice, mud, or water on the pavement may decrease the coefficient of friction between the rubber of the tires and the surface of the road to such an extent that the frictional force is insufficient to stop the automobile before it hits another object on the highway or to prevent a skid into the ditch.

If a car of average weight traveling 60 miles an hour is to be stopped in 8 seconds, the average force required is over 1000 pounds. This is 250 pounds on each of the four tires. No wonder some rubber is left on the pavement. The brakes must work at the rate of 50 horsepower. No wonder they sometimes fail to do what the driver wishes them to do. To go around a curve with a 200-foot radius at 30 miles an hour requires a sidewise frictional force of 250 pounds on each tire. The driver who tries to make this curve at 50 miles an hour should not be too greatly surprised when he fails. He is simply asking too much of his tires and the road. When speeding along at 50 miles an hour the car will have 250,000 foot-pounds of energy.

The rule of the road in at least one state is: "Be sure that you can stop in *your half* of the clear space ahead. Leave the other half for the other driver." Good advice is offered by: "Drive carefully. You may meet a fool." Be sure that this advice is not needed by the other drivers on the road just because you are looking for a thrill.

ANSWER THESE QUESTIONS

1. What are several examples of useful friction?
2. Why are automobiles streamlined?
3. Why does a locomotive engineer sometimes scatter sand upon the track?
4. Why are ashes sometimes placed upon icy sidewalks?
5. What causes a hotbox on a train?
6. Why would it be impossible to walk if there were no such thing as friction?
7. What are several ways of reducing friction in the moving parts of a machine?

MEASURING THE EFFICIENCY OF MACHINES

8. A filling-station attendant made the remark that the viscosity of the oil was good. What did he mean?

SOLVE THESE PROBLEMS

A

1. If the coefficient of friction between two surfaces is 0.2, what force will be required to pull 100 lb. horizontally along the surface?

2. If the coefficient of rolling friction of steel upon steel is 0.008, what force must the engine furnish to pull on a level track a train weighing 3000 tons?

3. If a force of 5 lb. applied horizontally will move a load of 25 lb. over a horizontal surface, what is the coefficient of friction between the load and the surface?

4. If a block of wood will slide down an inclined plane having a base 4 ft. long at a uniform velocity when one end of the board is 1 ft. higher than the other, what is the coefficient of friction between the block of wood and the inclined plane?

B

5. How much work is done when a force applied parallel to a plane causes a wooden block to move up a wooden inclined plane 30 ft. long and 6 ft. higher at one end than at the other, if the block weighs 400 lb. and the coefficient of friction is 0.5?

6. If 100 lb. of force acting parallel to a plane moves with uniform velocity a body weighing 180 lb. up a slope inclined 30° to the horizontal, what is the coefficient of friction?

AREA SEVEN

How Is the Efficiency of Machines Measured?

The universe is filled with various kinds of energy that man can use. He cannot create energy, but he can transform it. Water flowing along in a stream or over a waterfall has energy that may be used to turn a turbine or a water wheel. Heat causes water to change to steam that has energy. The invention of machines of various kinds has made possible the use of energy in many forms, but the machines themselves do not create energy; they transfer the energy from one body to another.

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Energy is transferred, not created. When we lift a stone with a lever, we transfer some of our energy to the stone by the use of a machine. Because of its changed position the stone possesses more energy and we possess less energy. The lever is used only to transfer the energy from our body to the stone. How much

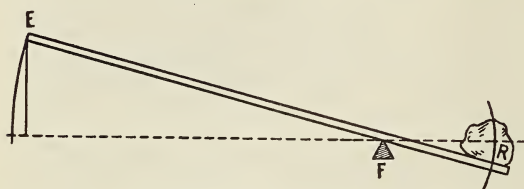


Fig. 116. A small effort properly applied can overcome a great resistance.

energy do we lose and how much does the stone gain? Suppose that the stone shown in Figure 116 weighs 500 pounds and that we apply a certain force at *E*. The stone

is two feet from the fulcrum and the force is 40 feet from the fulcrum measured along the lever. The T.M.A. = $\frac{40}{2}$ or 20; that is, one pound of force lifts 20 pounds of resistance. To lift 500 pounds of resistance, 25 pounds of force is required. This also means that the force moves 20 feet while the resistance moves one foot. If the vertical distance the stone moves is one foot, then the vertical distance the force moves is 20 feet. The energy that we put into the machine is $25 \times 20 = 500$ foot-pounds of work. The stone has 500 foot-pounds more of potential energy and we have given up 500 foot-pounds of energy. If friction is neglected, the energy given up by one body is equal to the energy received by the other body, or *the work put into a machine equals the work the machine gives out*. This is called the law of machines. The machine merely is the connecting agency between the two bodies. It transfers the energy from one body to another.

In the case of the wheel and axle, as shown in Figure 117, the force *E* moves $2\pi r$ while the resistance moves $2\pi r_1$. The work put into this machine equals $(2\pi r) E$ foot-pounds, and the output of the machine equals $(2\pi r_1) R$ foot-

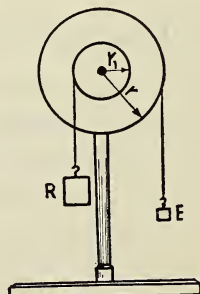


Fig. 117. The wheel and axle transfers energy.

MEASURING THE EFFICIENCY OF MACHINES

pounds when the wheel and axle makes one complete revolution, if r and r_1 are feet and E and R are pounds. This assumes that there is no energy lost in friction.

Efficiency. In all machines some of the energy is changed into heat energy because of friction. Therefore the useful output is not so much as the input. *The ratio of the useful output to the input is called efficiency*, which is given in per cent as follows:

$$\text{Efficiency} = \frac{\text{output (in work units)}}{\text{input (in work units)}}$$

For example, in Figure 118 suppose $R=500$ pounds, $E=110$ pounds, $r=5$ feet, and $r_1=1$ foot. When the wheel and axle makes exactly one turn, the input $= 2 \times 3.1416 \times 5 \times 110$ foot-pounds, and the output $= 2 \times 3.1416 \times 1 \times 500$ foot-pounds. The efficiency $= \frac{\text{output}}{\text{input}} = \frac{2 \times 3.1416 \times 1 \times 500}{2 \times 3.1416 \times 5 \times 110} = \frac{500}{550} = 0.90$ or 90 per cent. How may the efficiency of a block and tackle be calculated?

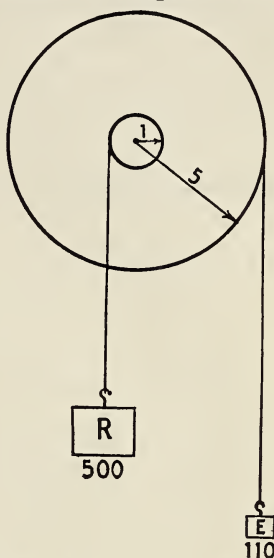


Fig. 118. Diagram showing wheel-and-axle efficiency.

Efficiency of an inclined plane. The efficiency of an inclined plane depends upon the coefficient of friction between the surface of the plane and the resistance. If the coefficient of friction is high, the efficiency is low. As with other machines, the efficiency is always found by dividing the product of the resistance and the perpendicular distance it moves, which is output, by the product of the force and the distance it moves, which is input. Suppose, as shown in Figure 119, a resistance of 500 pounds is lifted 5 feet by a force of 150 pounds

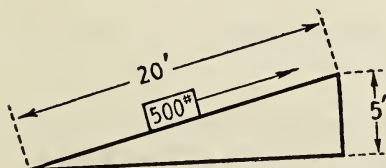


Fig. 119. An inclined plane used in illustrating the efficiency of a machine.

ENERGY AND ITS VEHICLE

moving 20 feet parallel with the plane. The output of the machine is $500 \times 5 = 2500$ foot-pounds. (This is the work required to lift the resistance up the plane to the required height.) The input is $150 \times 20 = 3000$ foot-pounds. Efficiency = $\frac{\text{output}}{\text{input}} = \frac{2500}{3000} = 83\frac{1}{3}$ per cent.

The efficiency of a wedge is very low because friction in the use of a wedge is extremely high. Likewise the efficiency of a jackscrew is rather low because friction is high. How can the efficiency of a jackscrew be found?

Perpetual motion. Since the energy input of a machine must furnish the useful energy output and also the energy lost in overcoming friction, the output of a machine cannot be so large as the input. There have been a great many attempts to invent a machine that would use its own output as input and thereby keep itself running indefinitely. Such a machine would be called a perpetual-motion machine. We should clearly see from our study of friction that no such machine can be devised. That we still hear occasionally of another attempt to accomplish this impossible task emphasizes the need of real scientific training for those who would hope to succeed as inventors.

ANSWER THESE QUESTIONS

1. Why is the efficiency of a wedge low?
2. Which simple machine is the most efficient? Why?
3. Is energy gained by the use of a machine?
4. Why is it impossible for a machine to have an efficiency of 100 per cent?
5. Is it possible to have a perpetual-motion machine? Why?

SOLVE THESE PROBLEMS

A

1. The handle of a windlass is 2 ft. long and the axle is 6 in. in diameter. If the efficiency is 80 per cent, how large a load applied at the circumference of the axle can a force of 20 lb. lift, applied at the end of the handle?



The men in this picture are rolling heavy logs against the strong current of a river. To do this they use peaveys in the same way in which a lever is used. The handle of the peavey serves as the lever and the log itself serves as a fulcrum.

2. A system of pulleys has five supporting strands. If the efficiency of the system is 80 per cent, how much of a load can be lifted with a force of 30 pounds?

3. The lever arm of a jackscrew is 2.5 ft. and the threads are two to an inch. If friction is neglected, how much of a load will 30 lb. applied at the end of the lever arm lift?

4. The length of an inclined plane is 20 feet. One end rests upon the ground and the other on the bed of a truck 3 ft. high. How much force will be required to slide a load of 500 lb. up the incline if the efficiency is 70 per cent?

5. If the sheaves of a differential pulley are 10 and 8 in., respectively, how much of a load can be lifted with a force of 50 lb. if the efficiency is 75 per cent?

6. A jackscrew is operated by a lever 2 ft. long. The pitch of the screw is $\frac{1}{8}$ inch. If 50 lb. are required to lift 8000 lb., what is the efficiency of the screw?

7. The radii of the wheels of a differential pulley are 24 and 22 in., respectively. If 120 lb. are applied to the rim of the larger pulley to lift a load of 1800 lb., what is the efficiency?

8. The front sprocket wheel of a bicycle has 32 sprockets, and the rear sprocket wheel has 8 sprockets. If the wheel has a diameter of 32 in., how far does the bicycle move forward when one complete revolution of the pedal occurs? How many miles per hour is the bicycle moving if the pedals are revolving 30 times a minute?

ENERGY AND ITS VEHICLE

SUMMARY

Work is accomplished when a force moves a body through space. The amount of work done can be calculated if the force and the distance the force moves are known, because work equals force multiplied by the distance it moves. The units of work derive their names from the units of force and space used. The most common units of work are the foot-pound, the gram-centimeter, and the dyne-centimeter, usually called the erg.

Power is the rate of doing work. The most common units of power used are the horsepower, the watt, and the kilowatt. A horsepower is the power used when 33,000 foot-pounds of work are done in one minute. A horsepower equals 746 watts. A kilowatt equals 1000 watts.

Energy is the ability to do work. When a body possesses energy, work has been done upon it so that its position, the condition of its molecules, or its motion has been changed. The energy that an object or a body possesses owing to its position or to the condition of its molecules is called potential energy, while the energy that it possesses owing to its motion is called kinetic energy. Since energy is the result of work, energy units and work units are the same; namely, foot-pounds, gram-centimeters, and ergs. Numerically potential energy is the product of the force required to place an object in its position and the distance through which it travels. Kinetic energy is one-half of the product of the mass and the square of the velocity.

Mechanical advantage is the ratio of the resistance a machine overcomes to the force that is used in overcoming the resistance. The theoretical mechanical advantage of a machine is the mechanical advantage when friction is not considered, and can be determined by dividing the distance the effort moves by the distance the resistance moves. The actual and theoretical mechanical advantages of a machine would be the same if friction could be eliminated.

Machines are devices used to transfer energy from one body to another. The law of machines is that the input energy equals the output energy. This law coincides with the law of conservation

PROBLEMS

of energy, which states that the energy given up by one body equals the energy received by the other body.

The efficiency of a machine is the ratio of the useful output to the input expressed in per cent. Owing to friction the useful output is never so large as the input, and the efficiency of a machine is always less than 100 per cent.

Would a person do work if he held a weight over his head?

Why is work done when a person digs a ditch or sweeps a floor?

When climbing a hill, why does an automobile do more work than when it travels the same distance over a level road?

If two like automobiles are going at different speeds over the same kind of road, which one develops more power?

When a gun is fired vertically, what kind of energy does the bullet possess when it first leaves the muzzle of the gun? when it reaches its maximum height? just before it reaches the ground?

How can a machine be made to lift a heavier object with a small force? When a machine is used to lift an object, which moves farther, the heavy weight or the small force?

Is the mechanical advantage of an automobile greatest when it is running in high gear, low gear, or intermediate gear?

SOLVE THESE PROBLEMS

1. How much useful work in foot-pounds would be done by a man who loads a truck with bricks if the truck holds 1000 bricks and each brick weighs 5 lb. and is lifted to an average height of $3\frac{1}{2}$ feet?

2. What horsepower does the man in problem 1 develop if he loads the bricks in 3 hours?

3. What horsepower would an elevator develop if it lifted the bricks in problem 1, 50 ft. in 10 seconds?

4. If the water from a falls drops 100 ft., what power is it capable of developing if 1000 cu. ft. of water falls every minute and the water weighs 62.4 lb. per cubic foot?

5. What is the theoretical mechanical advantage of an ice-cream freezer if the handle is 6 in. long, the axle is 2 in. in diameter, and the axle is fastened to a gear having 30 teeth that meshes with a gear having 10 teeth?

6. If the coefficient of friction between two bodies is 0.04, what force will be required to pull a 500-lb. weight over the horizontal surface if the force applied is parallel to the surface?

7. What is the efficiency of a machine if 5000 foot-pounds of work are applied to it and 3000 foot-pounds of work are delivered?

ENERGY AND ITS VEHICLE

INVESTIGATIONS

1. If a model or the transmission of an old automobile is available, investigate the gear ratios of the different speeds of the automobile.
2. Look at the differential of an old automobile and see why it is possible for the outside wheel to turn faster than the inside wheel when moving around a curve.
3. If a steam shovel is available, see whether you can identify the different types of machines and tell how the mechanical advantage is acquired.
4. See if you can set up systems of pulleys whereby you can acquire a mechanical advantage of 5.
5. If you live on a farm, calculate the theoretical mechanical advantage of the large hayfork used to unload hay.
6. Examine kitchen utensils such as a cream whipper or can opener, identify the type of machine, and determine how the mechanical advantage is derived.
7. Identify the simple machines found in a sewing machine, combine, and corn picker.



This picture shows a very hot blast of air being shot through molten pig iron in a Bessemer converter. This process involves a most intense kind of activity among the molecules.

UNIT FIVE

The Dance of the Molecules

A PERPETUAL DANCE MARATHON

You have read about dance marathons in which couples danced on and on for many weeks, day and night, with only a few minutes out of each hour for rest. You are now going to learn about a dance marathon that has been going on for ages with no time for rest. Instead of a few couples, however, billions of contestants are participating, and up to the present time the dance

THE DANCE OF THE MOLECULES

is just as vigorous as it was when it started. The dance is going on about you all the time, but you cannot see the contestants because they are too small. However, you can feel the effects of the dancing when you place your hands in hot water, hold them near a fire, or stand in the sun.

The dance referred to is the dance of the molecules, the continuous movement of the molecules that make up every substance. This dance, or molecular movement, produces heat. The faster the molecules of any substance dance, the hotter the substance becomes; and of course the slower they dance, the colder the substance becomes. The heat in a room, for example, is due to the movement of molecules in the air and is regulated by the speed at which the molecules dance. Although scientists have been able to slow them down considerably, they have never been able to stop the movement of molecules completely.

The purpose of this unit is to describe the various effects of dancing molecules upon matter, to show how the movements of molecules may be measured and controlled. In other words, the purpose is to explain the fundamental principles of heat as indicated by the questions enumerated below.

AREAS OF STUDY

- 1. What is the nature of heat?*
- 2. How does the change of temperature affect matter?*
- 3. How is heat measured?*
- 4. How does heat affect the state of matter?*
- 5. How is heat transferred from one place to another?*
- 6. What are good absorbers, radiators, and reflectors of heat?*
- 7. How does the study of meteorology aid an airplane pilot?*
- 8. What is the relation between heat and work?*

AREA ONE

What Is the Nature of Heat?

If we were to trace the development of civilization, we should find that man's progress has closely paralleled his control of heat. For a long time people knew little about heat except that heat comes from the sun. Little did they realize that heat could be changed into other forms of energy or that other forms of energy could be changed into heat. After scientists discovered the nature of heat, however, people began to use this important form of energy in many different ways.

What is heat? We have learned that all matter is made up of molecules. These molecules are continually in motion. Just as a body in motion has kinetic energy, so a molecule in motion has kinetic energy. The kinetic energy of the moving molecules of a body is the heat that the body possesses. To say that the heat of a body is increased means that the velocity of the molecules has increased; or to say that the heat of the body is decreased means that the velocity of the molecules has decreased. When heat is transferred from one body to another, the body that loses heat decreases its molecular motion and the body that gains heat increases its molecular motion. For example, when a piece of hot iron, such as a horseshoe being tempered by a blacksmith, is plunged into a bath of cold water, the iron gives up heat to the water; that is, the molecular motion of the iron decreases and the molecular motion of the water increases.

How is heat produced? The sun is the most important source of our heat, although we can produce heat by chemical and physical changes. We warm our homes and run our factories by using heat produced by burning coal, gas, wood, oil, and other combustible materials. The heat is released when the materials are chemically acted upon by the oxygen of the air. Heat is also produced when two objects are rubbed together or at the points where the moving parts of machines touch each other.

THE DANCE OF THE MOLECULES

For this reason we lubricate the moving parts of our automobile to reduce the heat produced by one part moving over another. When we feel the bulb of a lighted electric lamp, we realize that heat is produced also from electrical energy. We take advantage of the latter method of producing heat when we use an electric heater, a device that gives off heat from a conductor carrying a current of electricity.

The difference between heat and temperature. If we place a quart of water on a lighted gas burner and a gallon of water on a similar burner with the same size and kind of flame, we find that the quart of water becomes hot sooner than the gallon of water although the same amount of heat is added to both. This is to be expected because the quart of water contains fewer molecules than does the gallon. The molecules of the quart of water therefore increase in velocity more rapidly than the molecules of the gallon of water. Both the quart and the gallon receive the same amount of heat, but the smaller amount of water receives

This picture shows a baker removing a tray of sweet rolls from a large bakery oven. The thermometers at the left register the high temperatures on the inside of the oven.

Century Photos, Inc.



HOW CHANGE OF TEMPERATURE AFFECTS MATTER

more energy per molecule. Hence the faster movement of molecules in the quart causes it to become hot more rapidly. The heat gained by the gallon and the quart is a measure of the total energy gained by all the molecules in each and is the same in both cases. The temperature change is a measure of the kinetic energy gained by the individual molecules and is not the same in both cases. Since the kinetic energy of a molecule depends upon the square of its velocity, the faster-moving molecules have a higher temperature. In this example, then, heat represents the amount of kinetic energy and temperature represents the velocity of the molecules.

ANSWER THESE QUESTIONS

1. What is heat?
2. What are some important sources of heat?
3. What change in molecular movement occurs when a body is heated?
4. What changes in molecular movement occur when heat is transmitted from one body to another?
5. What is the difference between heat and temperature?
6. Why is more heat required to raise the temperature of a gallon of water than is necessary to raise the temperature of a pint of water when the temperature increase is the same in both cases?
7. Under what conditions will two bodies that have the same temperature possess the same amount of heat?
8. Under what conditions will two bodies having different temperatures also have the same amount of heat?

AREA TWO

How Does the Change of Temperature Affect Matter?

Heat has great influence upon objects in the environment, affecting both the status and the behavior of all forms of matter. It causes solids to change into liquids and liquids to change into gases, and sometimes solids to change directly into gases. Also it causes most solids and liquids and all gases to expand.

THE DANCE OF THE MOLECULES

Some effects of change of temperature. Telephone wires sag more in summer than in winter; an inflated toy balloon bursts on a cold day when it is brought from outdoors into a warm room; the

radiator of an automobile filled with cold water overflows slightly when the water becomes heated from the heat of the engine. These and other similar occurrences indicate that a rise in temperature causes most substances to expand.

We may perform several experiments in the classroom to show that a rise in temperature causes expansion. For instance, we may stretch a piece of fine nichrome wire tightly between the binding posts *a* and *a'* as shown in Figure 120 and place it in a 110-volt circuit. As the wire

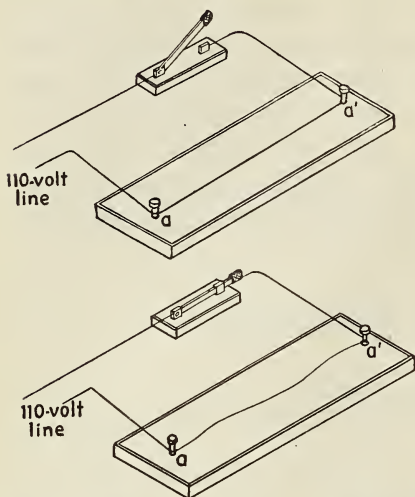


Fig. 120. Electrical apparatus for observing the effects of changing temperature.

becomes hot, it sags; that is, it grows longer. When the current is turned off, the wire cools and goes back to its original position and length. In another experiment we may pour cold water into a long-necked flask and mark the height of the water on the neck of the flask. If we heat the water we find that it expands and rises higher in the neck. If we heat the water still more it rises to the mouth of the flask and begins to run out. If we allow the water to cool after we have finished the experiment, it settles back to its original level.

If a mercury thermometer is thrust into hot water, the mercury drops slightly at first and then rises. The mercury drops because the glass that surrounds it expands before the mercury expands, and the bore of the glass becomes slightly larger, making more room for the mercury. The mercury rises as it becomes heated because, when once heated, it expands more rapidly than the glass and has less room in the glass.

HOW CHANGE OF TEMPERATURE AFFECTS MATTER

What causes the expansion of materials described above? The kinetic theory of heat explains the expansion due to increase of temperature. When a body is heated, the molecules are caused to move more rapidly. The faster they move, the more space they occupy, causing the body to become longer, wider, and thicker. Thus heating a body causes it to expand. When the body cools, the velocity of the molecules decreases and they occupy less space, thus allowing the body to contract.

MEASURING TEMPERATURE

Centigrade and Fahrenheit thermometers. Temperature has to do with the average amount of kinetic energy of the molecules. Since liquids expand when they are heated and contract when cooled, they are used in thermometers as indicators of temperature. The most common thermometers are made of mercury placed in a glass tube with a uniform bore and with a very good vacuum in the space above the mercury. Mercury is used because it expands uniformly and has a fairly low freezing point and a high boiling point. After the mercury is placed in a sealed glass tube as described above, the tube is placed in pure melting ice and the point where the mercury stands in the tube is marked. At an atmospheric pressure of 76 centimeters of mercury, pure ice always melts at the same temperature. The tube is then placed in the steam from pure boiling water at an atmospheric pressure of 76 centimeters of mercury and the point where the mercury stands in the tube is marked. Under the same pressure pure water always boils at the same temperature.

For the Centigrade scale the level of the mercury is marked 0° when the thermometer is in the melting ice and 100° when the thermometer is in the steam. The space between is divided into 100 equal parts, each of which measures 1° Centigrade (C.). Likewise the space below 0° and the space above 100° are divided into one-degree parts. The scale is called Centigrade because the two fixed points are 100 spaces apart. Such a scale is used in all parts of the world for scientific purposes and in many countries for domestic purposes as well.

THE DANCE OF THE MOLECULES

For the Fahrenheit scale the level of the mercury is marked 32° when the thermometer is placed in melting ice and 212° when the thermometer is placed in steam. The space between is divided into 180° divisions, each of which measures 1° Fahrenheit (F.), as do also all spaces above and below. The zero (0°) point is placed 32° below the freezing point. The Fahrenheit thermometer is used mostly for domestic purposes in English-speaking countries.

From Centigrade to Fahrenheit and vice versa. As an aid in converting the reading of a Centigrade thermometer into the reading of a Fahrenheit thermometer and vice versa, we should know the

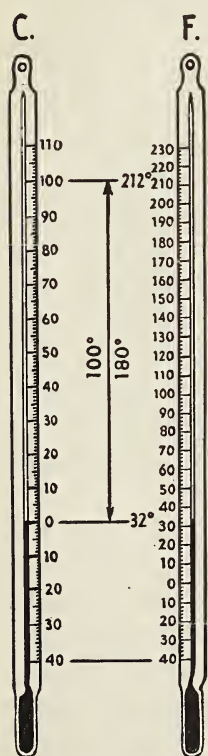


Fig. 121. Comparison of Centigrade and Fahrenheit scales.

relationship between the two scales. Figure 121 illustrates the markings on the two kinds of thermometers. Note that both stand at the freezing point, the Centigrade thermometer at 0° and the Fahrenheit thermometer at 32° . From freezing point to boiling point is 100° on the Centigrade scale and 180° ($212^{\circ} - 32^{\circ}$) on the Fahrenheit scale. Each degree on the Centigrade scale thus equals $180 \div 100$, or $\frac{9}{5}$ degrees on the Fahrenheit scale, but we cannot determine Centigrade readings simply by taking $\frac{5}{9}$ of Fahrenheit readings or determine Fahrenheit readings by taking $\frac{9}{5}$ of Centigrade readings. Zero reading on the Centigrade scale is the melting point of ice, and the zero reading on the Fahrenheit scale is 32° below the melting point of ice; therefore 32° must be subtracted from the Fahrenheit reading to make the starting point the same. The Fahrenheit reading minus 32 and multiplied by $\frac{5}{9}$ gives the Centigrade reading. If F. = Fahrenheit reading and C. = Centigrade reading, then $C. = \frac{5}{9} (F. - 32)$. Solving for F. in terms of C., the result is $F. = \frac{9}{5} C. + 32$.



Ewing Galloway

This picture shows a clinical thermometer being used to determine the body temperature of a hospital patient. If her temperature is normal the thermometer reading will be 98.6° . Marked variation from this would indicate that the patient is not yet well.

The clinical thermometer. The thermometer used by doctors and nurses is a mercury-in-glass type calibrated within the range of temperatures of the human body. The bore is very small at one point. When the mercury expands, it moves through the narrow place, but when it contracts, the mercury above the narrow part does not return to its original position. Thus the column of mercury remains at the highest point to which the temperature of the patient forced it to go, and the reading may be taken at the time or at any time later. Before the thermometer is used again, the mercury above the narrow place must be shaken down into the bulb. A nurse or physician readily lowers the mercury by jerking the thermometer in the hand.

The metal thermometer. The metal thermometer does not contain a liquid but instead contains a coil made of two strips of metal. The inside strip is made of brass, and the outside strip is made

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of steel. One end of the coil, as shown in Figure 122, is fastened to the frame at *F*; the other end is fastened to a perpendicular rod *PR* upon which is a semicircular strip *MRN*. A small cylinder *C* is fastened to the strip, generally with a silk thread,

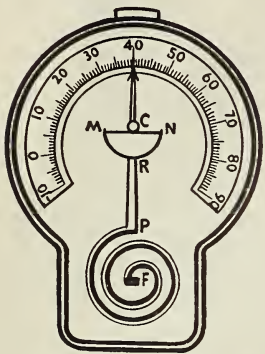


Fig. 122. Diagram of the usual metal spring thermometer.

and a pointer is attached to the cylinder. The thread is wrapped around the cylinder in such a way that it causes the pointer to move whenever the strip *MRN* moves. Since brass expands more than steel, the coil partially uncoils when the temperature rises, causing the strip *MRN* to move to the left. The thread around the cylinder is wrapped in such a way that it causes the cylinder to revolve clockwise and the pointer to indicate a higher temperature. Likewise, when the temperature decreases, the brass contracts more than the steel

and causes the coil partially to wind up. This phenomenon moves the pointer in the opposite direction, indicating a lower temperature. The dial of the thermometer is calibrated by means of a standard mercury-in-glass or gas thermometer.

The maximum and minimum thermometer. One of the most accurate thermometers is the maximum and minimum thermometer used by the United States Weather Bureau. This thermometer is so named because it consists of two thermometers assembled in one device, both of which are calibrated according to the Fahrenheit scale. The maximum thermometer uses mercury as the expanding and contracting liquid and the scale is calibrated in single-degree divisions from 20° to 120°. Resting on this column of mercury inside the tube is a small indicator that fits snugly enough to be affected by friction. When the mercury expands with rising temperature it pushes the indicator up the tube. When the mercury recedes with falling temperature the indicator remains at the point of highest registration. To lower the indicator the user whirls the thermometer or attracts it with a magnet.

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The minimum thermometer uses alcohol as the expanding and contracting liquid and is calibrated in single degrees from 60° below zero to 120° above zero. As in the maximum thermometer, a small indicator rests upon the liquid inside the tube. In this case, however, the indicator drops as the alcohol recedes with falling temperature. When the alcohol expands it passes around the indicator, leaving it at the lowest point. Thus the indicator always indicates the lowest temperature to which the thermometer is subjected. To raise the indicator, the user merely whirls the thermometer as before, or attracts it with a magnet.

The thermograph. The recording thermometer, or thermograph, is a metal thermometer used in connection with a cylinder rotated by clockwork. The cylinder is covered with a sheet of graph paper upon which is marked a temperature scale and the days of the week subdivided into hours, as shown in Figure 123. The metal thermometer consists of a coiled spring made of material that is sensitive to temperature changes. An inked stylus or pen is attached to the coiled spring by a long lever. As temperature changes cause the thermometer to coil and uncoil, the stylus records the various changes of temperature upon the rotating cylinder.

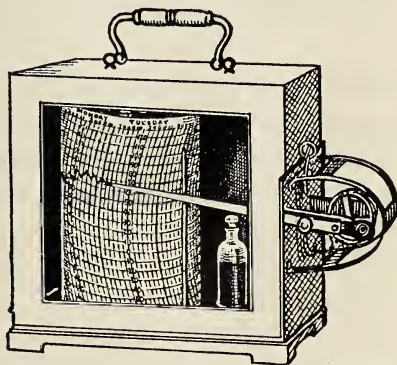


Fig. 123. Metal thermometer operated by clockwork for recording purposes.

MEASURING EXPANSION CAUSED BY HEAT

The coefficient of linear expansion. Objects expand a definite amount for each degree in change of temperature. The designer of machines, steel bridges, and other metal structures must know accurately how much the material expands or contracts under the change of temperature to which the machine or structure is subjected. Much experimental work has been done in finding the



The girl in this picture has placed a metal rod in a long tube that she fills with steam. A measuring device on the end of the tube enables her to determine the linear expansion of the rod with the rise in temperature caused by the heat of the steam.

linear (length) expansion of materials. It has been found that equal lengths of the same kind of solids always expand the same amount under the same increase of temperature and that unequal lengths expand by amounts directly proportional to their lengths for the same increase in temperature. Two pieces of aluminum of uniform density one foot long expand 0.000023 foot when the temperature is increased 1° C., whereas two feet of aluminum expand (0.000023×2) or 0.000046 foot. Materials differ as to the amount they expand with the same increase in temperature. One foot of aluminum expands 0.000023 foot with an increase of 1° Centigrade, whereas one foot of copper expands only 0.000016 foot. The increase per unit length per degree of temperature is called the coefficient of linear expansion. If we let K represent the coefficient of linear expansion, L_1 the original length of the object, L_2 the final length, t_1 the original temperature, and t_2 the final temperature, we may measure the coefficient of linear expansion

as follows: $K = \frac{L_2 - L_1}{L_1(t_2 - t_1)}$.

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Example. Suppose a piece of lead 3 feet long having an initial temperature of 20° Centigrade is heated until its temperature is 120° Centigrade, and its length is then found to be 3.0084 feet. What is the coefficient of linear expansion of lead?

Solution. To solve this problem we substitute 3 feet for L_1 , 3.0084 feet for L_2 , 20 for t_1 , and 120 for t_2 , in the foregoing equation as follows:

$$K = \frac{3.0084 - 3}{3(120 - 20)} = 0.000028.$$

Occasionally, when we know the coefficient of linear expansion K of a substance, the original length L_1 of an object made from the substance, the original temperature t_1 , and the final temperature t_2 , we may wish to use the equation in finding the final length of the object L_2 . In such a case, we look up the coefficient of linear expansion in Table VII in the Appendix and substitute known quantities in the foregoing equation modified as follows:

$$L_2 = KL_1(t_2 - t_1) + L_1.$$

Some practical examples of linear expansion. The difference in linear expansion of metals may be demonstrated by a compound bar such as is used in the thermostat that controls the temperature of many homes. This thermostat, illustrated in Figure 124, consists of two strips of metal b and b' that have widely different coefficients of expansion and are riveted together. This compound bar is an automatic switch in the electric circuit that controls the heating mechanism. As the temperature increases, the uneven expansion of the two metals causes the hand a to move upward and to make a contact at S . When this occurs, the electric current moves

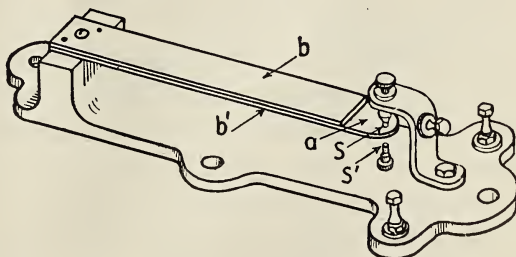


Fig. 124. Diagram showing essential parts of a thermostat. Operation of the thermostat depends on linear expansion.

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the bar, causing it to shut off the heating mechanism. Likewise, a downward bend causes the hand to make a contact at S' and thus causes the heat to be turned on.

If the balance wheel of a watch is all made of one material, a rise of temperature causes its circumference to expand. This ex-



Fig. 125. Balance wheel of a watch.

pansion causes the oscillations of the wheel to be slower. Good balance wheels of watches are made of two kinds of metals riveted together, as shown in Figure 125. The inner part is made of a metal that does not expand so much as the outer metal expands. Therefore the parts of the rim that are free move inward when expansion takes place owing to change of temperature. If the metals are properly selected and adjust-

ments are carefully made, the oscillation of the wheel may be kept nearly constant.

Coefficient of volume expansion. If a cube of aluminum one centimeter on each edge has an initial temperature of 20° Centigrade and its temperature is raised to 21° Centigrade, the cube expands in length, width, and thickness. The coefficient of linear expansion of aluminum is 0.000023. Therefore, if the cube expands 0.000023 centimeter on each edge with an increase of 1° Centigrade, it now measures $(1+0.000023)$ centimeter on each side. Its original volume was $1 \times 1 \times 1 = 1$ cubic centimeter. Now its volume is $(1+0.000023)^3 = 1.000069001577012167$ cubic centimeters. Discarding all decimals beyond the sixth we have 1.000069 cubic centimeters as the new volume, and 0.000069 cubic centimeter as the change in volume. This number is exactly three times the coefficient of linear expansion. For practical purposes we may use the following rule for determining volume expansion: *The coefficient of volume expansion is equal to three times the coefficient of linear expansion.*

Example. How much does 1000 cubic centimeters of copper increase in volume if the temperature change is from 20° Centigrade to 150° Centigrade?

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Solution. The coefficient of linear expansion of copper is 0.000017; therefore its volume coefficient of expansion is $0.000017 \times 3 = 0.000051$. $1000 \times (150 - 20) \times 0.000051 = 6.63$ cubic centimeters increase.

Some interesting facts about the expansion of liquids and gases.

Most liquids expand much more than solids. A thousand cubic centimeters of water expands about 40 cubic centimeters when its temperature is changed from 0° Centigrade to 100° Centigrade, but the same volume of brass expands only 5.4 cubic centimeters. Liquids such as alcohol and oils expand much more than water.

Water expands when heated and contracts when cooled, occupying the least amount of space (greatest density) when the temperature is 4° Centigrade. If cooled or warmed from 4° Centigrade, it expands. Thus the top water of a pond sinks to the bottom in cold weather and the less dense water rises to the top, until the entire body of water is 4° Centigrade. The top water then cools until it reaches a temperature of 0° Centigrade and freezes. The layer of ice separates the water beneath it from the cold air and tends to prevent freezing to great depths.

All gases expand as their temperatures rise. The remarkable thing about the expansion of gases is that their coefficient of volume expansion is nearly nine times as much as that of water. We may demonstrate this by confining some air in a tube with a drop of mercury as in Figure 126. The bore being

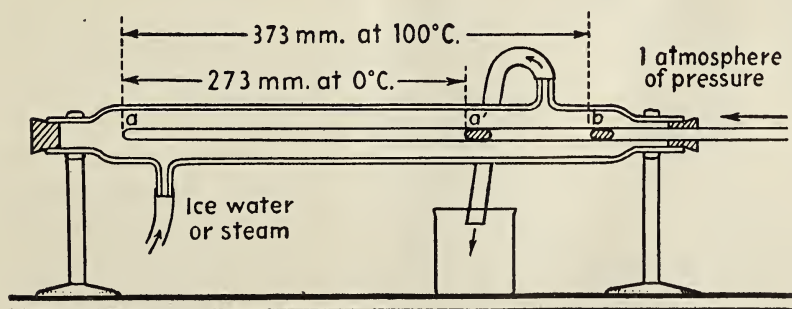


Fig. 126. Apparatus for determining the volume coefficient of the expansion of gas.

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uniform, the volume is directly proportional to the length of the column of air. Circulate ice water (0° Centigrade) through the outer tube and measure the column of air aa' . Suppose it measures 273 millimeters. Next send steam at 100° Centigrade through the tube and the gas will expand to ab . The distance ab is found to be 373 millimeters. The gas has expanded 100 millimeters for 100° Centigrade change or 1 millimeter for 1° Centigrade change. The original volume was represented by 273 millimeters; therefore, it has increased $\frac{1}{273}$ of its volume for 1° Centigrade change. Its coefficient of expansion, then, is $\frac{1}{273}$.

Gay-Lussac made a study of the expansion of gases and found that all gases have approximately the same coefficient of expansion, namely, $\frac{1}{273}$ of their volume at 0° Centigrade when the pressure is kept constant.

Temperature and pressure. Why does the pressure in an automobile tire increase when the air in the tire increases in temperature? The automobile tire does not become larger when the air in it increases in temperature. Instead, the volume remains

constant and the pressure of the air increases. We can demonstrate this fact in the following experiment. We fill the flask D with dry air and connect it to an open-arm manometer tube as in the left-hand drawing in Figure 127. We surround the flask with cracked melting ice at 0° Centigrade and adjust the mercury in the manometer tube to be at the same level

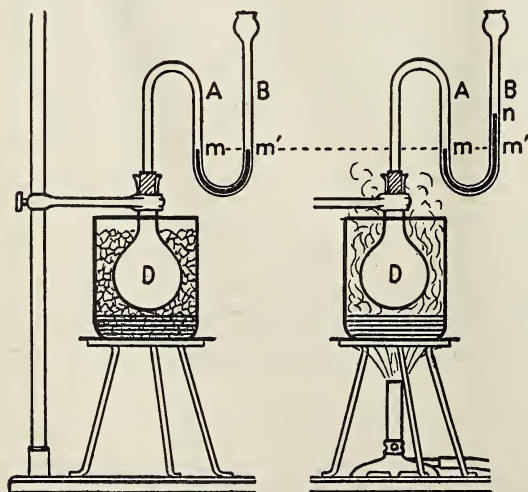


Fig. 127. Equipment for experiment showing the effect of increasing temperature on the pressure of a confined gas.

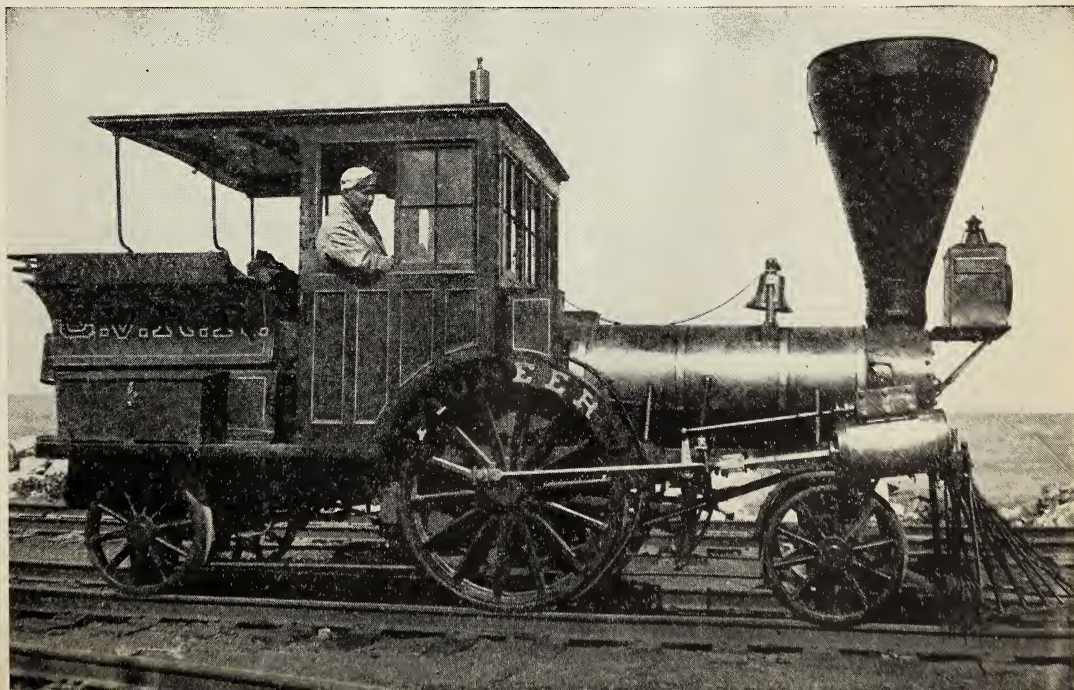
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mm' in the two arms. Since the pressure at both ends of the mercury column is the same, the air in D is at atmospheric pressure. Now we repeat the experiment using steam instead of ice. We surround the flask D with steam at 100° Centigrade and pour enough mercury in at tube B to keep the level in the closed arm A at m as before. This keeps the volume constant. The difference of the level of the mercury at n in this experiment and at m in the first experiment is a measure of the increase of pressure due to the increase in temperature from 0° Centigrade to 100° Centigrade. When the volume is constant, the increase in pressure (coefficient of pressure expansion) per degree Centigrade is approximately $\frac{1}{273}$ of the pressure of the gas at 0° Centigrade, the same numerical value as the coefficient of volume expansion. The pressure is caused by the bombardment of the molecules against the sides of the container. The rise in temperature increases the velocity of the molecules, and thus increases also their kinetic energy.

What is the lowest possible temperature? If the temperature of any gas is decreased, the molecules have less kinetic energy because their velocity is decreased. A decrease in temperature

The locomotive shown in this picture is the "Pioneer," one of the earliest successful steam locomotives. The pistons that drive its wheels depend for their power on the expansion of steam. This famous locomotive still travels "under its own steam."

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of 1° Centigrade, when the volume remains the same, causes the gas to decrease in pressure by $\frac{1}{273}$ of the pressure at 0° Centigrade. If the temperature drops 10° Centigrade—that is, to -10° Centigrade—the pressure decreases $\frac{10}{273}$ of the original pressure at 0° Centigrade. It is easily seen that the gas loses all of its pressure if the temperature is decreased 273° Centigrade from 0° Centigrade; that is, if temperature of gas drops to -273° Centigrade. If the gas has no pressure, the molecules have ceased to have velocity. If there is no motion of molecules, there is no heat, for a body has no heat when its molecules are not in motion. If the molecules cease to have motion at -273° Centigrade, there can be no further decrease of motion or pressure or heat. This point, then, the lowest possible temperature, is called absolute zero. Absolute zero is 273° below 0° Centigrade. A temperature scale is sometimes used which starts at the point where the molecules have no motion. On this scale, called the

Absolute scale, -273° is taken as 0° or the starting point of the scale. A comparison of the Centigrade and Absolute scales is shown in Figure 128. The Centigrade scale can easily be converted into the Absolute scale by the addition of 273° to the Centigrade reading. If T stands for Absolute readings, and C for Centigrade readings, then $T = C + 273^{\circ}$ or $F + 459.4^{\circ}$.

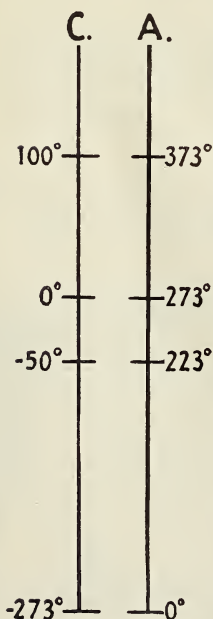


Fig. 128. Centigrade and Absolute scales.

Charles's and Gay-Lussac's laws. Earlier in the book we found a discussion of Boyle's law, the law being stated as follows: *If the temperature remains constant, the volume is inversely proportional to the pressure.* Expressed in the form of an equation, the law was as follows: $\frac{V_2}{V_1} = \frac{P_1}{P_2}$.

Temperature is not always constant, however. We have learned from the preceding pages of this unit that changes in temperature cause changes in volume or in pressure. We

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need two more laws to describe the changes that occur when the volume or pressure is constant and the temperature is subject to change.

In 1787 Charles, a French scientist, stated one of the laws as follows: *If the pressure of a gas is constant, the volume is directly proportional to the absolute temperature.* The formula for this law is $\frac{V_1}{V_2} = \frac{T_1}{T_2}$.

Gay-Lussac, another French scientist, stated a third law as follows: *If the volume of a gas is constant, the pressure is directly proportional to the absolute temperature.* Expressed as a formula, $\frac{P_1}{P_2} = \frac{T_1}{T_2}$. The two laws are usually called the first and second laws of Charles. Gay-Lussac, in his experiment and the statement of this law, verified the work of Charles.

The same three factors are involved in each of the laws; namely, temperature, pressure, and volume. If one is constant, the other two vary according to the formula that applies to them. It is not surprising, then, that the three formulas can be combined into a single formula.

In the three formulas, T_1 =first absolute temperature, T_2 =second absolute temperature, P_1 =first pressure, P_2 =second pressure, V_1 =first volume, and V_2 =second volume. The three formulas of the laws of gases may be combined into one, as follows: $\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$. If any five terms of the formula are known, of course, the sixth term can be found. If two of the terms are always constant ($P_1 P_2$, $V_1 V_2$, or $T_1 T_2$), we are concerned only with three known terms and one unknown term in using the single formula.

Example. The pressure of an automobile tire is 50 lb. per square inch, when the temperature is 10° Centigrade. What is the pressure when the temperature is increased to 40° Centigrade?

Solution. As the tire remains the same size, the volume is constant. The temperature may be changed to the Absolute scale. ($T = 273 + C.$), $T_1 = 273 + 10 = 283$, $T_2 = 273 + 40 = 313$.

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In the combined formula $\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$, the volume drops out because it is the constant term.

Then $\frac{P_1}{T_1} = \frac{P_2}{T_2}$ or $\frac{50}{283} = \frac{P_2}{313}$. $P_2 = 55.3$ pounds.

ANSWER THESE QUESTIONS

1. How does the kinetic theory of heat explain the expansion due to increase of temperature?
2. When a body cools, what change in molecular action takes place?
3. Does a thermometer measure heat or temperature? Explain why this is so.
4. Why is mercury commonly used in thermometers?
5. What are the important steps in making a thermometer?
6. How does the Centigrade scale differ from the Fahrenheit scale?
7. What is the formula for changing a Centigrade reading to a Fahrenheit reading?
8. What is meant by the coefficient of linear expansion?
9. In what practical ways is the compound bar used?
10. What is the relationship between the coefficients of linear and volume expansion?

This beautiful bridge carries countless tons of traffic across the Ohio River. The engineers who built it had to consider the expansion and contraction of metal at different temperatures. The ends of the bridge are therefore of flexible construction.

Ewing Galloway



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11. At what temperature does water have its greatest density?
12. How does the coefficient of volume expansion compare with the coefficient of pressure expansion?
13. Why is absolute zero -273° or -459.4° F.?
14. What are the three laws that deal with temperature, pressure, and volume of gases?
15. What is the combined formula that may be used to find temperature, pressure, or volume?

SOLVE THESE PROBLEMS

A

1. If the temperature of a patient in a hospital is 37.5° C., does he have fever if his normal temperature is 98.6° F.?
2. A Fahrenheit thermometer registers -20° on a cold winter day. What does a Centigrade thermometer register?
3. What is the Fahrenheit temperature of a gas that is -60° C.?
4. If a gas is at a temperature of 40° C., what is its temperature on the Fahrenheit scale?
5. A copper wire is 200 ft. long at 10° C. How long will it be at 30° C.?
6. A steel steam pipe 300 ft. long at 68° F. has steam turned into it so that its temperature rises to 368° F. How much does the pipe expand? How is this expansion taken care of in a large steam heating system?
7. What will the volume of 500 cu. ft. of air at 0° C. be if the temperature is increased to 30° C., the pressure remaining constant?
8. An aluminum vessel holds one gallon at 0° C. How much will it hold at 90° C.?
9. An automobile tire has 40 lb. pressure per sq. in. when the temperature of the air is 20° C. What will be the pressure if the temperature is raised to 40° C., the volume remaining constant?
10. Five hundred cc. of gas is under pressure of 90 cm. of mercury at 20° C. What will its volume be at 0° C. and 76 cm. of mercury?
11. A gas tank contains 20 cu. ft. of gas under a pressure of 200 lb. per square inch. The temperature remaining constant, how many cubic feet will the gas occupy under normal atmospheric conditions (14.7 lb. per sq. in.)?
12. If 75 cu. in. of gas at 40° C. and under a pressure of 15 lb. per sq. in. is placed in a container in which the volume and pressure can be varied, what will be the temperature of the gas if it is compressed to 12 cu. in. and its pressure is increased to 60 lb. per square inch?

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B

13. If the temperature change on a certain day is 40°F. , what is the temperature change Centigrade?
14. Change $-273^{\circ}\text{Centigrade}$ to Fahrenheit.
15. If the temperature of the water in the radiator of an automobile is 180°F. , what is the temperature on the Centigrade scale?
16. If the distance between the boiling point and the freezing point of a mercurial thermometer is 10 in., what is the length of the space that represents one degree on the Fahrenheit scale?
17. What is the length of the space that represents one degree on the Centigrade scale of the thermometer in the preceding problem?
18. A copper wire is 1 mi. long at 0°C. How long will it be at $30^{\circ}\text{C.}?$
19. Two steel rails are each 66 ft. long at 37°F. How much space must be allowed between them when placed end to end to allow for a summer temperature of 104°F. if they are laid when the temperature is $37^{\circ}\text{F.}?$
20. If the length of a steel rod at 0°C. is 150 cm. and the length of a copper rod at 0°C. is 149 cm., at what temperature will both be the same length?
21. It is required to double the pressure of helium gas contained in a steel cylinder by heating it. To what temperature Centigrade will it have to be heated if the initial temperature of the gas is $27^{\circ}\text{C.}?$
22. One hundred liters of hydrogen at 10°C. is under a pressure of 750 mm. of mercury. Find the volume of the gas when the temperature is changed to 0°C. and the pressure is increased to 800 mm. of mercury.

AREA THREE

How Is Heat Measured?

Whereas the temperature of a body is the measure of kinetic energy of the individual molecules, heat is the measure of the total energy of all the molecules of the body. For example, a bucket filled with water may have the same temperature as a large lake, because the molecules in both are moving at the same velocity; but it will have less heat because it has fewer molecules and hence less heat energy. The temperature of a body depends upon the average kinetic energy of its molecules, whereas the

HOW HEAT IS MEASURED

heat of a body depends not only upon the average kinetic energy of its molecules but also upon the number of molecules that are in motion in the body.

Two units for measuring heat. There are two units of heat, one defined in British units and the other in metric units. The British thermal unit (B.t.u.) of heat is the quantity of heat energy required to raise the temperature of one pound of water one degree Fahrenheit. A pound of coal of average quality has about 12,000 B.t.u. of heat. If all of the heat energy from a pound of coal were transferred to 12,000 lb. of water (approximately 1412 gallons), the temperature of the water would rise 1° Fahrenheit. If it were transferred to 300 lb. of water (approximately 353 gallons), it would cause the temperature of the water to rise 40° Fahrenheit.

The calorie is the unit of heat in metric units. It is defined as that quantity of heat energy which raises the temperature of one gram of water one degree Centigrade. If 1000 grams of water (one liter) is placed over a Bunsen burner until the temperature of the water has increased 5° Centigrade, 5000 calories of heat energy have been transferred from the gas to the water.

We are familiar with the name *Calorie* that designates the unit of heat used in measuring food values. The name of that unit, however, is spelled with a capital *C* and does not designate the metric unit defined above. The scientist calls it a large Calorie, because it is 1000 times as large as the small calorie used in the metric system. If a food substance has 100 Calories, the heat from it, produced by burning, will cause the temperature of 1000 grams of water to increase from 0° to 100° Centigrade.

Measuring the effect of heat upon temperature. Which contains more heat, a pound of water or a pound of iron at the same temperature? It is quite noticeable that it requires a longer time to heat a kettle of water to a certain temperature over a flame than it does to heat the same weight of iron, or some other metal, to the same temperature. We can illustrate this fact by taking

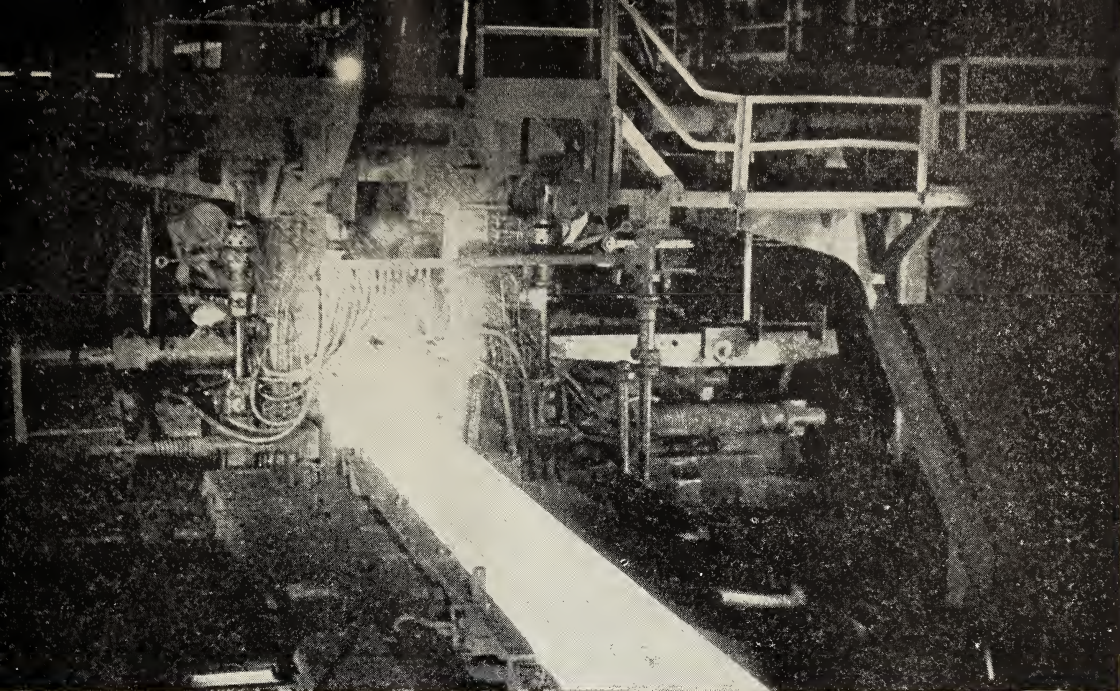
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a tin cup filled with water and an equal weight of iron at the same temperature as the water and placing each of them over a Bunsen burner regulated so that the flames of the two burners are the same. The iron soon becomes too hot for us to place a finger upon it, while at the same time the water is comfortable on the hand. We should need to leave the water over the burner much longer than the iron in order to raise its temperature to that of the iron. In fact, water requires more heat than almost any other substance to produce a given increase in temperature.

Specific heat. As the above experiment shows, there is a difference between the quantities of heat required to change two different substances of the same weight from one temperature to a higher temperature. Because water requires more heat than other substances to produce a given temperature change, we make water the basis for comparison. The relative amount of heat required for other substances is designated by the term specific heat. *The number of heat units required to raise one unit mass of a substance a certain number of degrees compared to the number of heat units required to raise one unit mass of water the same number of degrees is called specific heat.*

Specific heat is often defined numerically as the number of calories required to raise one gram of a substance 1° Centigrade, or the number of B.t.u. required to raise one pound of a substance 1° Fahrenheit. Thus if we say that the specific heat of water is one (1) and the specific heat of aluminum is 0.21, we mean that one gram of water requires one calorie to raise its temperature 1° Centigrade, while one gram of aluminum requires only 0.21 calories to raise it 1° Centigrade. Of course, if one gram of water cools 1° Centigrade, it gives off one calorie of heat while one gram of aluminum gives off 0.21 calorie.

How can the specific heat of a substance be found? In all cases where heat energy is transferred from one body to another, the heat energy of the hot substance goes to the cold substance until both have the same temperature. If a piece of iron at 120°



Carnegie-Illinois Steel Corporation

This picture shows one step in the process of making a steel beam. While it is being formed the heat of steel is very great, causing it to give off many hundreds of calories. If this steel beam were placed in water, some of the water would become steam.

Centigrade is dropped into a pail of water at 10° Centigrade, the iron gives up the same number of calories as the water and pail take in. The iron stops giving off calories when both iron and water have the same temperature. The number of calories of heat the iron gives up to the water is determined by multiplying the weight of the iron by its change of temperature, and this product by its specific heat, which is designated by S . Likewise, the number of calories of heat taken up by the water is determined by multiplying the weight of the water by its change of temperature, and this product by its specific heat, which is always one. It is an easy matter to find the specific heat of a substance because the specific heat of water is, by definition, one. If the specific heat of iron is desired, all that we need to know is the initial temperature of the hot iron, its weight, the final temperature of the mixture after the iron has been placed in the water and cooled, and the weight of the water. We can then write out the equation and solve for S , as in the example on page 322.

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Example. Suppose 50 grams of iron, initial temperature 120° Centigrade, is placed in 110 grams of water at 15° Centigrade and the final temperature of the mixture is 20° Centigrade, what is the quantity of heat one gram of iron gives up when its temperature is decreased by 1° Centigrade, or what is the specific heat (S) of iron?

Solution. Heat given up by iron $= 50(120 - 20)(S)$ calories.

Heat taken in by water $= 110(20 - 15)1$ calorie.

Since the quantity of heat the water takes in equals the quantity of heat the iron gives up, the resulting equation is as follows:

$$50(120 - 20)S = 110(20 - 15)1.$$

Collecting, $5000S = 550.$

$$S = \frac{550}{5000} = 0.11 = \text{specific heat of the iron.}$$

We must keep in mind that the water is in a container that absorbs some of the heat from the iron. We find the amount of heat that the container absorbs by multiplying its weight by the change of temperature by its specific heat. This amount is added to the heat the water takes in.

Example. Suppose 50 grams of metal, initial temperature 120° Centigrade, is placed in 110 grams of water at 15° Centigrade; the final temperature of the mixture is 21° Centigrade, and the container used is copper, specific heat 0.095, and weight 100 grams. What is the specific heat of the metal?

Solution. Heat taken in = heat given up.

Let S = the specific heat of the metal.

$110 \times (21 - 15) \times 1 = 660$ calories, heat taken in by the water.

$100 \times (21 - 15) \times 0.095 = 57$ calories, heat taken in by container.

$50 \times (120 - 21) \times S =$ heat given up by the metal.

Therefore, $660 + 57 = 4950S$

$$\text{or } 4950S = 717$$

or $S = 0.14$, specific heat of the metal.

HOW HEAT IS MEASURED

Errors may appear in the preceding experiment as they do in many experiments; therefore the values of the specific heat of substances found in the manner described may not be absolutely correct. The accepted values for the specific heats of common substances are found in Table XI of the Appendix.

ANSWER THESE QUESTIONS

1. What is the difference between temperature and heat and how is each measured?
2. What are the following units of measure, and how is each used: B.t.u., calorie, and Calorie?
3. Which is the larger unit, a B.t.u. or a calorie?
4. Which gives more heat when burned, a pound of soft coal or a pound of hard coal? (Consult Table VIII in the Appendix.)
5. What is meant by the specific heat of a body?
6. Why is water used as the basis of the definition of specific heat?
7. What are the important steps in using the method of mixtures to find the specific heat of an object?
8. Why does an aluminum kettle get hot more quickly than does an iron or a copper kettle under the same conditions? (Consult Table XI in the Appendix.)

SOLVE THESE PROBLEMS

A

1. A piece of metal that weighs 50 g. and has a temperature of 99°C . is placed in 198 g. of water at a temperature of 21°C . The water is contained in a calorimeter that weighs 101 g. and has a specific heat of 0.1. The resultant temperature of the water, calorimeter, and iron is 22.4°C . Find the specific heat of the metal.
2. What is the resultant temperature when 500 g. of lead at 100°C . is placed in 400 g. of water at 20°C . if the water is contained in a copper calorimeter that weighs 200 grams? (Use the specific heat table in the Appendix for the specific heat of lead and copper.)
3. How many B.t.u. will be required to heat 10 lb. of water from 40°F . to 200°F .?
4. What is the resultant temperature if 500 g. of water at 20°C . is mixed with 400 g. of water at 90°C .?

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B

5. If 300 g. of water at 90°C . is mixed with 150 g. of water at 20°C ., what is the resultant temperature?

6. A piece of iron that weighs 500 g. and has a temperature of 99.8°C . is placed in 500 g. of water at a temperature of 15°C . If the water is in a copper container that weighs 100 g., what is the resultant temperature?

7. If a cubic foot of gas gives up 1100 B.t.u. when it burns, how many pounds of water can be heated from 15°C . to 100°C . provided the water is in a copper container that weighs 4 lb. and the efficiency is 60 per cent?

8. A copper calorimeter that weighs 100 g. contains 200 g. of water at 18°C . An iron ball that weighs 80 g. is taken from a furnace and dropped into the water. The temperature of the water is raised to 30°C . On the basis of these facts, what is the temperature of the furnace?

AREA FOUR

How Does Heat Affect the State of Matter?

From experience we know that when we apply enough heat to ice we cause the ice to form water, and when we apply enough heat to water we cause the water to form steam. On the other hand, when we allow steam to cool it forms water, and when we remove heat from water the water changes to ice. Thus we see that the state of water, whether a solid, a liquid, or a gas, depends upon its temperature. The same is true of other forms of matter. By sufficiently decreasing or increasing the temperature of any object or substance, we can change its state of matter.

What is the temperature of melting ice? If a pan filled with ice is placed over a flame, the ice begins to melt. If a Centigrade thermometer is placed in the ice water, it will indicate that the temperature of the mixture remains $0^{\circ}\text{Centigrade}$ until all the ice is melted. The water should be stirred constantly so that the temperature is uniform throughout the mixture. This simple

HOW HEAT AFFECTS THE STATE OF MATTER

experiment shows that the heat which the flame gives up to the ice is not used in raising the temperature of the ice, but is used in melting the ice. The heat energy that is used to melt the ice pulls the molecules of the ice farther apart from each other, changing the solid to a liquid—that is, the ice to water. This change in position of the molecules causes a change of potential energy of the molecules. Therefore the heat energy (molecular kinetic energy) used to melt ice is given to the molecules in the form of potential energy. Had it been given to the molecules in the form of kinetic energy, the temperature of the ice would have changed but the ice would not have melted.

It can be shown by an experiment that the amount of heat required to melt one gram of ice at 0° Centigrade without changing its temperature is approximately 80 calories (79.8). This number is called the heat of fusion of ice (in the metric system). In the B.t.u. or English system 143.6 B.t.u. are required to melt one pound of ice at 32° Fahrenheit without changing the temperature. Most of the substances that melt require heat to change them from a solid to a liquid without increasing their temperature, but each substance requires a different amount of heat. *The amount of heat required to change one gram of a substance from a solid to a liquid without increasing its temperature is called the heat of fusion of that substance.*

All that has been said in the above paragraphs applies, in reverse order, when water freezes. For example, when water at 0° Centigrade freezes, it gives off 80 calories of heat per gram without getting colder. Since any substance requires heat to change it from a solid to a liquid without changing its temperature, the same amount of heat is given off when the liquid is changed into a solid without a change of temperature.

How is the heat of fusion of ice found? The heat of fusion of ice is found by the mixture method, just as the specific heat of any substance is found. A known weight of ice is placed in a given weight of water at a known temperature, the mixture is stirred until all the ice is melted, and the temperature of the mixture



Ewing Galloway

This picture illustrates a familiar use of ice cubes. The tea is cooled and the ice is melted in the same manner as in the experiment for finding the fusion of ice.

is then taken. The water gives up the heat that is required to melt the ice. It must be remembered that the temperature of water which is formed by the melting ice is also warmed from 0° Centigrade to the final temperature of the mixture. The heat given off by the water equals the heat required to melt the ice plus the heat required to warm the melted ice from 0° Centigrade to the final temperature of the mixture.

Example. Suppose 20 grams of ice at 0° Centigrade is placed in 180 grams of water at 31° Centigrade and the resultant temperature of the mixture is 20° Centigrade. What is the heat of fusion of ice?

Solution. If we let X = number of calories required to melt one gram of ice, then $20X$ = calories required to melt 20 grams of ice. The ice water formed from the melting ice is raised from 0° Centigrade to 20° Centigrade, requiring $20 \times 20 \times 1 = 400$ calories of heat. The heat required to melt the ice and raise it to 20° Centigrade is $(20X + 400)$ calories. The heat the water gave up is $180 \times (31 - 20) \times 1 = 1980$ calories.

HOW HEAT AFFECTS THE STATE OF MATTER

$$20X + 400 = 1980.$$

$$20X = 1580.$$

$$X = 79 \text{ calories, the heat of fusion of ice.}$$

In the foregoing problem the weight of the container of the water was not considered. The following example will illustrate the method of solution when the container is considered.

Example. Suppose that 40 grams of ice at 0° Centigrade is placed in 200 grams of water at 45° Centigrade and that the resultant temperature is 25° Centigrade. What is the heat of fusion of the ice if the container weighs 100 grams and has a specific heat of 0.1?

Solution. Heat taken in = heat given up. If we let X = the heat of fusion of ice, then $40X$ = the heat taken in to melt the ice. $200 \times (45 - 25) \times 1 = 4000$, the number of calories given up by the water, and $100 \times (45 - 25) \times 0.1 = 200$, the number of calories given up by the container. $4000 + 200 = 4200$, the total number of calories given up. $40 \times (25 - 0) \times 1 = 1000$, the number of calories taken in by the water. Subtracting 1000 from 4200 we obtain 3200, the number of calories taken in to melt the ice.

$$40X = 3200.$$

$$X = 80 \text{ calories, the heat of fusion of ice.}$$

Some practical uses of heat of fusion. When water freezes, each gram of the water gives off 80 calories of heat. This loss of heat helps to explain why land bordering large bodies of water has a more even temperature than land some distance away. It also helps to explain why tubs of water placed in a cellar help to keep fruits and vegetables from freezing in winter. The water gives off heat when freezing and thus tends to keep the vegetables and fruits in the cellar safe.

Ice placed in a refrigerator keeps the food cool. When one gram of ice melts, it takes in 80 calories of heat from the contents of the refrigerator. The heat that melts the ice comes from the air surrounding the ice. This air is chilled and becomes more dense. It then moves to the lower part of the refrigerator

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and the warmer air rises up past the ice. Thus a circulation of air is continually taking place over the ice and past the contents of the refrigerator. The food loses its heat to the circulating current of air, which in turn loses heat to the melting ice. If it were not for the heat of fusion, ice would be worthless as a means of keeping food cold. Since many foods become unfit for use when exposed too long to warm temperatures, ice helps us to have good food and thus to maintain good health.

Liquids expand when they change to solids. Ice occupies more space than an equal mass of water; hence when water freezes, it exerts tremendous pressure. If 1000 cubic centimeters of water is frozen, the resulting block of ice will measure more than 1000 cubic centimeters. For this reason water pipes, automobile radiators, and other containers often burst when water freezes. Moreover, since ice occupies more space than water, it has a lower density and therefore floats in water. The specific gravity of ice is about 0.92, and therefore about $\frac{9}{10}$ of the volume of a piece of ice is under water when the ice floats. An iceberg when viewed from a boat appears smaller than it actually is because only about $\frac{1}{10}$ of it extends above the surface.

Water freezing in the crevices of rocks expands, breaks the rock, and helps to cause the formation of soil. On the other hand, farmers sometimes have their wheat and grass frozen out by the freezing and expanding of the water in the soil which pushes the roots of the plants out of the ground. Freezing and thawing are big factors in our public road system. To minimize the effects of freezing and thawing, road contractors see to it that the road bed is well drained so that the water will not remain under the road bed. When this precaution is not taken, portions of paved roads are pushed upward by the pressure of freezing water and are cracked or broken.

Cast iron, type metal, and a few other substances expand when they solidify. This fact is important for many industries. In foundries, for instance, iron castings are made by the pouring of molten iron into molds. As the iron cools and solidifies, it

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expands slightly, fitting tightly into every detail of the mold. Obviously, if this slight expansion did not occur, the finished product might not duplicate exactly the pattern of the mold. In the manufacture of printing type this expansion helps to provide the accurate detail of the finished type.

Can the freezing point of water be lowered? When pressure is applied to water, the freezing point is lowered. This is to be expected because the pressure tends to keep the water from expanding. For every 15 pounds per square inch (one atmosphere) of pressure, the freezing point of water is lowered about 0.007° Centigrade. This is not a large change, and it is readily seen that great pressure would be required to lower appreciably the temperature at which water freezes. The effect of pressure upon the freezing point of water can be shown by a simple experiment. A block of ice rests upon two supports as illustrated in Figure 129. A wire with a heavy weight at each end is placed over the ice. After several hours the wire passes through the ice and falls to the ground. The ice, however, remains in one piece upon its supports. The explanation of this experiment is simple. The pressure of the wire upon the ice lowers the freezing point at the point of contact between the wire and the ice. At that point, then, the ice melts. As the wire sinks into the ice the water above the wire freezes because the pressure which caused it to melt has been removed.

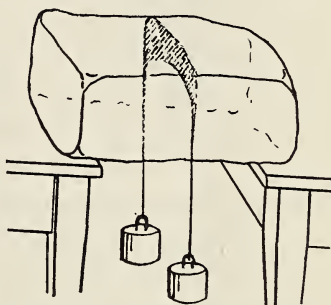


Fig. 129. Experiment demonstrating the melting of ice by pressure.

The freezing point of water is also lowered when any substance is dissolved in it. It is lowered much more readily in this way than by pressure. If salt is added to water until no more can be dissolved, the water does not freeze until the temperature falls to about -20° Centigrade. Alcohol is placed in the water of automobile radiators because the freezing point of

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the mixture is thereby lowered. Sulfuric acid in the water keeps storage batteries from freezing until the temperature falls much below 0° Centigrade.

It is even possible to cool a liquid below its freezing point without freezing the liquid. We may place distilled water, which has been recently boiled to remove the air, in a test tube, for example, and surround the tube with a mixture of salt and ice. If we keep the water perfectly quiet, its temperature falls several degrees below 0° Centigrade without freezing. If we drop a small piece of ice into the water or stir the water, however, ice forms immediately and the temperature rises to 0° Centigrade. A liquid is said to be supercooled when its temperature reaches a point below its normal freezing point.

Salt lowers the freezing point of water, and on this account it melts ice on which it is placed. Salt mixed with ice when making ice cream, for example, causes the ice to melt. Since each gram of ice that melts takes up 80 calories of heat (mostly from the cream that is freezing), the melting ice absorbs enough heat from the cream to cause it to freeze.

What happens when water boils? If we pour some water into a flask and place the flask over a flame, something happens to the water. First we notice air bubbles being driven from the water because the heat is driving the dissolved air from the water. Next we notice small bubbles starting at the bottom and gradually rising as heat continues to rise from the flame. As these bubbles get nearer the top of the water, they increase in size. At first the bubbles collapse before they reach the top, and cause a singing sound. After the heat of the flame has been applied for some time, however, the bubbles reach the top and cause the surface of the water to be agitated. The bubbles are not air but vapor. They are made up of molecules of water that are moving a little more rapidly than the surrounding molecules of water; therefore they are exerting more pressure. Because the density of the bubbles is much less than that of water, the buoyant force on them pushes them to the surface.

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Bubbles form on the surface of the water and boiling takes place because the pressure exerted by the molecules of vapor is greater than the atmospheric pressure and the pressure caused by the weight of the water. *The boiling point of a liquid is the temperature at which the vapor pressure is equal to the atmospheric pressure upon the surface of the liquid.*

Boiling point and pressure. If a thermometer is placed in boiling water under one atmosphere of pressure, it records 100° Centigrade and never gets any higher, even though additional heat is given to the water by the flame. Suppose a flask is partially filled with water that is brought to the boiling point. After the water has boiled, a stopper is inserted in the mouth of the flask and the flask is inverted as shown in Figure 130. If cold water is poured over the flask, the water vapor is condensed within the flask, thus reducing the pressure. Boiling then takes place at a lower temperature, depending upon the decrease in pressure. This is the logical conclusion from the definition of the boiling point, for under such conditions less vapor pressure is necessary to overcome the atmospheric pressure. On the other hand, if air is forced under pressure into a vessel, the vapor pressure must equal the pressure at the surface before boiling takes place. More heat must be created to increase the temperature and the vapor pressure before boiling will take place.

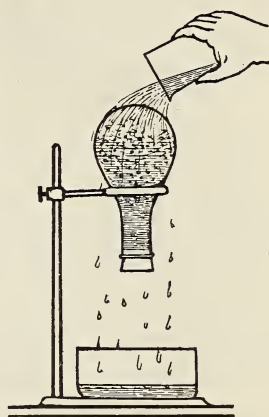


Fig. 130. Atmospheric pressure and the boiling point.

It is often desirable to change the boiling points of liquids by reducing or increasing the pressure above them. For example, in the manufacture of maple sirup it is desirable to lower the boiling point of the sugar solution from which the sirup is made. Maple sirup is made by the process of boiling away some of the water from the sap which comes from maple trees. In modern factories this sap is placed in boilers in which the pressure is

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lowered. The solution then boils at a lower temperature with a saving of time and heat. In high altitudes where the low atmospheric pressure causes a low boiling point, a long time is required

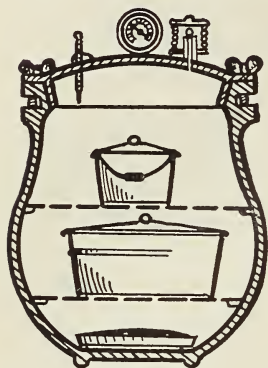


Fig. 131. Cross section of an ordinary pressure cooker.

to cook foods by boiling. This is overcome by use of a pressure food cooker such as the drawing shows in Figure 131. It is a closed boiler in which the steam is confined until a pressure of 20 pounds to 30 pounds per square inch is reached. This pressure raises the boiling point, and the food cooks in much less time. The pressure food cooker is also used for canning vegetables in which it is desirable to destroy the bacteria quickly by a high temperature.

What is the temperature of water in a steam boiler? If the vapor is not allowed to escape after it reaches the surface of the water in a closed vessel, it exerts a pressure downward against the surface of the water. This raises the boiling point of the water. If enough heat is added to the water to cause more vapor to form and escape, the water vapor causes a still greater pressure upon the surface, and this increased pressure causes the boiling point to rise again. This process can be kept up as long as it is desirable to have the boiling point continue to rise. The water in a boiler can thus be brought to any desired temperature. In high-pressure boilers, the temperature of the water is around 170° Centigrade when the pressure gauge registers 100 pounds. If the boiler is weak in some spot, however, so that it breaks or cracks open, the pressure is reduced so rapidly and the water changes to steam so quickly that an explosion takes place.

Not all liquids have the same boiling point. When most substances, such as sugar or salt, are dissolved in water, the boiling point of the solution is increased above that of pure water. Different liquids have different boiling points at the same pressure. Alcohol

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(ethyl) boils at 78.3° Centigrade under normal atmospheric pressure, while lead boils at 1525° Centigrade and hydrogen (liquid) boils at -253° Centigrade. Alcohol mixed with water in an automobile radiator boils away before the water does, because the boiling point of alcohol is lower.

Distillation. If the vapor from a boiling liquid is cooled below the boiling point, it condenses into the liquid state again. This explains the process called distillation, by which it is easily possible to purify water containing bacteria or dissolved mineral substances. The impure water is boiled and the steam is conducted through a cooled pipe, where it condenses into water again and is collected. The impurities are left behind. If two liquids having different boiling points, such as alcohol and water, are mixed and heated, the mixture begins to boil at a temperature somewhere between the respective boiling points of the pure liquids. The alcohol vaporizes much more rapidly than the water at first, but gradually as the alcohol vaporizes and boils away the temperature rises and eventually becomes nearly equal to 100°

The students in this picture are distilling crude oil. The parts of the oil with the lower boiling points vaporize first and are condensed as they pass through the condensing tube. The distillation of a liquid in parts is known as fractional distillation.



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Centigrade. If the vapor that comes off first is condensed, it will be found to be nearly pure alcohol. This process, called fractional distillation, is an important step in separating crude oil, which is a mixture of liquids with different boiling points, into such fractions as naphtha, gasoline, kerosene, and many other refined products useful in home and industry.

Heat of vaporization. If a thermometer is placed in water that is being heated over a flame, the temperature will rise steadily until the boiling point is reached and then remain constant. The heat from the flame is still being taken in by the water, but the heat is now being used to change water into vapor rather than to increase the temperature of the water. If the thermometer is held in the vapor, just above the surface of the water, the temperature will be found to be the same as that of the water itself.

The amount of heat energy required to cause one gram of water at 100° Centigrade to change into vapor (steam) at 100° Centigrade is 540 calories; the amount required to change one pound of water at 212° Fahrenheit into vapor without a change in temperature is 970 B.t.u. This is the heat of vaporization of water. When steam condenses and forms water, this heat energy is given off just as water gives off heat energy when it freezes.

The heat that is given off when steam condenses is called the heat of condensation, which, of course, is numerically equal to the heat of vaporization. The heat of vaporization of water is so large that it plays a very important part in our lives.

In a steam heating system the steam is formed in a boiler in the basement and sent to the rooms of the house through pipes where it condenses in the radiators, as shown in Figure 132. Every gram of steam that condenses gives off 540 calories

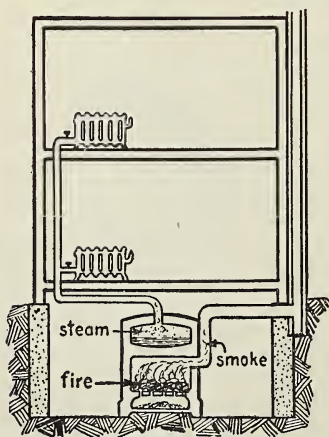


Fig. 132. Cross section of house showing steam heating system.

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of heat to the rooms. This fact explains why a steam heating system heats a cold room more quickly than a hot-water system. Also, since a gram of steam at 100° Centigrade has 540 calories more heat than a gram of water at 100° Centigrade, a burn caused by a mass of steam is much more severe than one caused by an equal mass of boiling water.

Measuring the heat of vaporization or condensation. The mixture plan, like the one used in determining the heat of fusion of ice, is used in the laboratory to measure the heat of vaporization. The first step is to put some cold water that is below room temperature into a calorimeter.

Next, we pass enough steam into the cold water with a delivery tube, as illustrated in Figure 133, to cause the temperature of the mixture of condensed steam and water to be about as far above room temperature as the cold water was below it. At this point we know the initial temperature of the cold water and the steam, the final temperature of the cold water and the

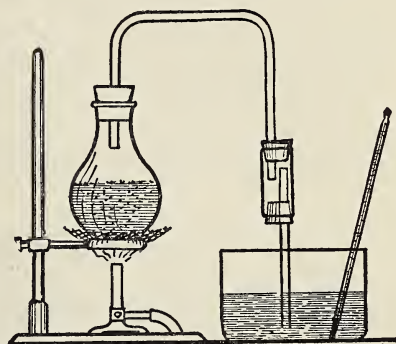


Fig. 133. Diagram showing apparatus used for laboratory experiment with vaporization.

condensed steam, the weight of the calorimeter, and the weight of the water before and after the steam is added. The heat of vaporization can be calculated by use of the following rule: The heat lost by the condensed steam plus the heat lost by the water formed by the condensed steam equals the heat gained by the cold water plus the heat gained by the calorimeter. We can express these quantities in symbols and write the proper equation by following the explanation given for determining the heat of fusion of ice on page 327. Errors must be eliminated as far as possible. The best way to eliminate errors is to make sure that our measurements of weights and temperatures are accurate. Some of the heat escapes from the steam and does not pass

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into the water, and some of the heat from the room passes into the calorimeter. The errors caused by these factors are reduced by bringing the mixture to a temperature as far above room temperature as the cold water and the calorimeter were below room temperature in the beginning.

A solid can change directly to a vapor without first changing to a liquid. If a few crystals of iodine are placed upon a watch glass and heated gently, the crystals change directly to a gas. Snow and ice evaporate slowly when below 0° Centigrade. The process of changing from a solid directly to a gas is called sublimation. Arsenic and camphor sublime at normal atmospheric pressure. Sometimes arsenic is used in the coloring matter of wallpaper. This is injurious to the health because it sublimates and the occupants of the room inhale the gas. Moth balls placed in rooms sublime at room temperature. The gas formed by sublimation penetrates the upholstering and carpets in the room.

EVAPORATION OF LIQUIDS

Evaporation is a cooling process. The molecules of a liquid are always in motion. Not all of them have the same speed at any one instant; some will be moving very much more rapidly than others. The ones with high speeds at one instant may be the ones with low speeds at the next instant. The average speed of all the molecules in a body of liquid remains constant so long as the temperature is constant. A rise in temperature is merely an indication of a higher average speed of all the molecules. Some of the molecules very near the surface of the liquid move toward the surface with a higher than average speed. Some of these faster ones escape from the liquid altogether and become vapor molecules. Those with average or lower than average speeds do not get away from the attraction of the molecules below them. It is the fastest not the average ones that evaporate. If the average speed of all the members of a track team is computed and then some of the fastest runners are taken off the team, the average speed of the team is

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thereby lowered. So it is with the molecules of a liquid. As the fastest and the hottest molecules evaporate, the average speed and temperature of the remaining ones are lowered.

That evaporation is essentially a cooling process can easily be demonstrated. If we place thermometers in shallow vessels of water, alcohol, and ether, we find that the temperatures of the three liquids are lower than the temperature of the air about them. We find that the ether is cooled most, the alcohol next, and the water the least. If the vessels stand for some time, the ether evaporates most rapidly, the alcohol less rapidly, and the water the least rapidly. After considering these facts, we are not surprised to note the following boiling points: ether, 35° Centigrade; alcohol, 78° Centigrade; water, 100° Centigrade.

An important factor in determining the rate of evaporation is the air movement, or lack of it, over the evaporating surface.

Evaporation is a great aid to athletes. The breeze passing over the bodies of these runners offsets the natural heat of their bodies by the cooling effect of evaporation.

Ewing Galloway



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If a breeze blows over the vessels of liquid mentioned before, the rates of evaporation, as indicated by the thermometers, are considerably increased. This is explained as follows: The molecules which have just evaporated accumulate near the surface. Some of them return to the liquid and thus give back to the liquid the heat that they took away when they evaporated. This condensation, or return of vapor molecules to the liquid, obviously takes place most rapidly when there are a great many vapor molecules near the liquid surface. A steady current of air blowing over the surface carries the vapor molecules away nearly as fast as they appear. This prevents the heating due to condensation and emphasizes the cooling due to evaporation.

Pressure of a saturated vapor. Saturation with vapor results when the rate of condensation is the same as the rate of evaporation. The number of molecules per unit volume required to produce a state of saturation depends upon the liquid used and upon the temperature. The saturated vapor exerts a pressure that can be measured with considerable accuracy. If a mercury barometer is set up and a little ether is placed in the mouth of the tube, the ether rises to the top of the mercury column and evaporates into the vacuum at the top. The mercury column falls a considerable distance, which represents the pressure of the saturated vapor. If the tube is warmed, the mercury drops still farther, and the temperature at which the vapor pressure forces the mercury down to the level of the mercury in the dish is the boiling point of the ether, by the definition of boiling point.

What causes rain, dew, and frost? The higher the temperature of air, the more vapor it holds. If the air is saturated at 20° Centigrade, it holds 17.2 grams of water vapor per cubic meter. If the air is saturated at 12° Centigrade, it holds 10.57 grams of water vapor per cubic meter. If the air is saturated at 20° Centigrade, and cooled to 12° Centigrade, it loses $17.2 - 10.57 = 6.63$ grams of water vapor per cubic meter by the vapor condensing and forming water. This 6.63 grams of water usually forms a

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cloud, or fog, in which the droplets are so small that they are suspended in the air or fall very, very slowly. Under conditions of more rapid condensation these droplets may grow until they become large enough to be called raindrops. If the condensation occurs at a temperature below the freezing point, water vapor is changed directly into snowflakes.

It is noticeable that cold water poured into a glass on a warm humid day causes vapor of the water in the air to condense on the glass. This is because the cold water lowers the temperature of the glass to a point where the surrounding atmosphere cannot hold all the moisture it contained. The moisture that the air cannot hold gathers on the glass. The same thing happens with leaves, grass blades, and other objects when they are cooled at night by radiation of heat. As they cool to a temperature at which the surrounding air cannot hold all of its moisture, the excess moisture condenses on the leaves and the grass, and is called dew. The bark of the tree does not lose its heat so rapidly and does not cool the surrounding air to the temperature at which it becomes saturated. If the temperature at which the air cannot hold all of its moisture is below the freezing point, the vapor freezes as it is deposited and is called frost.

What is meant by "dew point"? The temperature at which the air becomes saturated and the water vapor begins to condense is called the dew point. For example, the air at 20° Centigrade has 13.5 grams of water vapor in it per cubic meter. This is the quantity of water vapor that the air can hold down to 16° Centigrade. If the temperature reaches 16° Centigrade, dew forms. In this case 16° Centigrade is the dew point. If the air held only 8.21 grams of water vapor per cubic meter, dew would not form until the temperature had dropped to 8° Centigrade, which is the temperature at which air becomes saturated if it holds 8.21 grams of water vapor per cubic meter. If the dew point happens to be the freezing point or below, the dew freezes. Precipitation cannot take place unless the air is cooled to a temperature below the dew point.



Ferdinand Hirsh

The high humidity of a sultry summer day forces people to the beaches where they take advantage of lake breezes and cool water. This picture shows a typical beach scene.

What is meant by humidity? Humidity refers to the moisture content in air. In considering its moisture content, scientists use two types of humidity, absolute humidity and relative humidity. Absolute humidity is the weight of the moisture content in a unit volume of air. This humidity is usually expressed in grams per cubic meter or in grains per cubic foot, a grain being one seven-thousandth of a pound. In order to find the absolute humidity, we merely cause a given volume of air to pass through a drying agent, such as concentrated sulfuric acid or calcium chloride, and determine how much the drying agent increases in weight.

Relative humidity is the ratio of the absolute humidity, or the moisture content of air at any given time, to the total moisture content the air would hold at the same temperature if saturated. In order to find the relative humidity, we first find the absolute humidity, or the actual moisture content, and divide this content by the amount of moisture the air would hold if saturated at the same temperature.

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Table IX in the Appendix shows the moisture content of air at the saturation point at different temperatures. Suppose that the absolute humidity of the air on a certain day is 18 grams per cubic meter at a temperature of 24° Centigrade. Table IX tells us that at 24° Centigrade at the saturation point air would hold 21.55 grams per cubic meter. Therefore we divide 18 by 21.55 and find that the relative humidity is 83.53 per cent.

When the relative humidity is low, as in a closed room in winter, evaporation from the body takes place rapidly and causes us to feel cold. To make us feel comfortable the room must be heated to a higher temperature than would be required if the air were supplied with adequate moisture. When the relative humidity is high, as on a sultry day in summer, evaporation from the body takes place slowly and causes us to feel hot. During very warm weather, therefore, it is desirable to remove some of the moisture from the air in the room, by a system of air conditioning.

The relative humidity is measured by an instrument known as a hygrometer, of which there are several forms. One form, sometimes called a psychrometer, consists of two thermometers, as shown in Figure 134, one being known as a wet-bulb thermometer and the other as a dry-bulb thermometer. The wet-bulb thermometer, which is shown at the right in the drawing, is so named because its bulb is covered with a wet cloth. Since evaporation takes place from the cloth and produces a cooling effect, the wet-bulb thermometer registers lower temperatures than does the dry-bulb thermometer. The less moisture there is in the air, the faster the evaporation from the cloth and the lower the temperature readings on the wet-bulb thermometer. Thus the difference in readings between the two thermometers depends upon the moisture in the air. By experiment with this

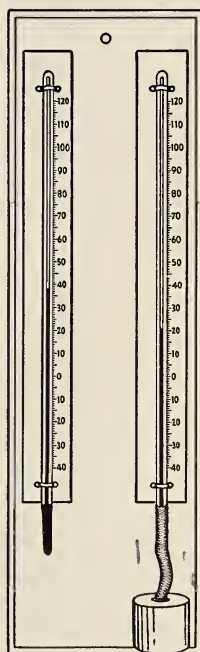


Fig. 134. Dry-bulb and wet-bulb thermometers.

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hygrometer, scientists have developed a table showing the relative humidity as indicated by the differences in the readings of the wet-bulb and dry-bulb thermometers.

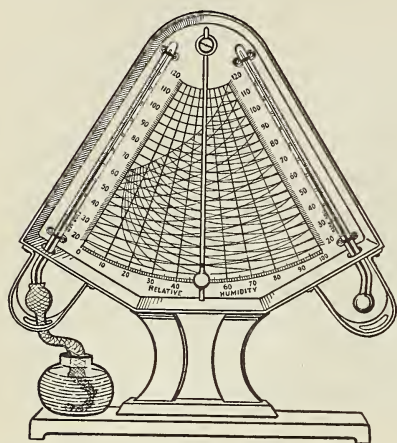


Fig. 135. Diagram of a hygrodeik, an instrument used for measuring humidity.

A second hygrometer, which is a modification of the hygrometer described on page 341, is the hygrodeik, shown in Figure 135. This instrument shows the relative humidity directly and hence requires no reference to a table.

Another type of hygrometer, a type frequently used in aviation, consists of strands of human hair. The hairs change in length with varying quantities of moisture in the air and operate levers that move a pointer on a dial.

The dial is calibrated to show the relative humidity directly without the aid of a table. This instrument includes a stylus that records the relative humidity upon a revolving cylinder, and this provides a continuous picture of the humidity throughout various intervals of time.

ANSWER THESE QUESTIONS

1. How is the temperature of ice affected when it is heated?
2. What is meant by the heat of fusion?
3. How can the method of mixtures that is used in finding the specific heat of a substance be used to find the heat of fusion of ice?
4. In what two ways can the freezing point of water be lowered?
5. What causes the bubbles at the surface of water that is boiling?
6. How is the boiling point of water affected by pressure?
7. What is the process of fractional distillation?
8. What is meant by the heat of vaporization?
9. What molecular action takes place in a liquid when it cools by evaporation?
10. What is meant by dew point and by what process is the dew point determined?
11. What is the difference between absolute and relative humidity?

HOW HEAT AFFECTS THE STATE OF MATTER

SOLVE THESE PROBLEMS

A

1. When 100 g. of steam at 100°C . is condensed, how many calories of heat are given up?
2. How much water at 50°C . will be required to melt 100 g. of ice at 0°C .?
3. If 50 g. of ice at 0°C . is placed in 500 g. of water at 90°C ., what will be the resulting temperature?
4. Three hundred g. of iron at 180°C . is placed upon a large piece of ice. How much ice will be melted?
5. How many B.t.u. will 50 lb. of ice at 32°F . take from a refrigerator in changing to water at 32°F .?
6. When 5 tons of water at 0°C . freezes, how many B.t.u. are given off?
7. If 150 g. of ice at 0°C ., 600 g. of water at 0°C ., and 1500 g. of water at 100°C . are mixed, what is the final temperature?
8. Find the relative humidity if the temperature is 20°C . and the dew point is 10°C . (Use Table IX in Appendix.)
9. What is the dew point if the temperature is 30°C . and the relative humidity is 70 per cent?
10. A room is 10 meters $\times$ 8 meters $\times$ 3 meters. It has a relative humidity of 60 per cent and a temperature of 21°C . What is the weight of the water vapor in the room?
11. When 100 g. of steam at 100°C . is condensed and cooled to water at 0°C ., how many calories of heat are liberated?
12. When 100 g. of steam at 100°C . is condensed, cooled to water at 0°C ., and then changed to ice at 0°C ., how many calories of heat are given up?
13. If 50 g. of steam at 100°C ., 500 g. of water at 50°C ., and 50 g. of ice at 0°C . are mixed, what is the resulting temperature?
14. How many grams of ice at 0°C . can be melted with 100 g. of steam at 100°C .?

B

15. If a piece of iron that weighs 300 g. is heated to 100°C . and dropped into a hole cut in a block of ice that has a temperature of 0°C . and allowed to remain there until it is the same temperature as the ice, how much ice will be melted?
16. How many B.t.u. will be required to melt 50 lb. of ice?
17. What will be the final temperature when 100 g. of ice at 0°C . is mixed with 1000 g. of water at 100°C .?

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18. One thousand g. of ice at 0°C . is dropped into 2000 g. of tea at 20°C . How much of the ice is melted by the tea if it is in a container that weighs 1000 g. and has a specific heat of 0.2? (Assume the specific heat of the tea to be 1.)

19. In a steam heating system 2000 g. of steam at 100°C . passes through a radiator in one hour, condenses, and leaves the radiator as water at 85°C . How many calories of heat were given off to the room per hour?

20. If the heat value of coal is 14,000 B.t.u. per pound, how many pounds of coal will need to be used in a boiler to change 500 lb. of water at 40°F . into steam at 212°F . provided the boiler is 40 per cent efficient?

21. How many pounds of steam at 212°F . are required to raise the water in a swimming pool to a temperature of 70°F .? The pool is 40 ft. long, 30 ft. wide, and 8 ft. deep. The water in the pool is 6 ft. deep, its temperature 40°F ., and the steam is allowed to pass into the water and condense.

22. One hundred g. of steam at 100°C ., 100 g. of lead at 200°C ., 5000 g. of water at 60°C ., and 800 g. of ice at 0°C . are mixed. What is the resultant temperature?

23. A room is 6 meters long, 3 meters wide, and $2\frac{1}{2}$ meters high. The temperature is 22°C . How many kilograms of water vapor will be required to cause the relative humidity to be 60 per cent?

AREA FIVE

How Is Heat Transferred from One Place to Another?

It is often inconvenient or impossible to have the source of heat located where the heat is desired. For example, heat and hot water are desired in a bathroom, but it is inconvenient and undesirable to provide these right in a bathroom. Consequently, some arrangement must be made to furnish the heat in a convenient place and to conduct the heat and the heated water to the bathroom. To do this in a satisfactory manner, we must understand how heat is transmitted and how this may be done most efficiently. But we are not always concerned with the

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problem of transferring heat; sometimes we wish to keep heat in or to keep it out—to prevent it from being transferred. We shall be interested in this area, therefore, in three different kinds of heat transfer; namely, convection, conduction, and radiation.

CONVECTION

How a hot-air heating system works. One type of heating system that operates on the basis of convection is the hot-air heating system, shown in Figure 136. This system consists of a furnace, large air pipes that lead from the top of the furnace to different rooms of the house, and other pipes that lead from certain rooms and from out-of-doors to the lower part of the furnace. When the air over the fire is heated, it rises to the rooms through the air pipes leading from the top of the furnace because it is pushed upward by the colder and denser air in the pipes leading into the bottom of the furnace. There must be a cold-air pipe from the room returning to the furnace so that there can be complete circulation of the cold air from the room to the furnace and hot air from the furnace to the room. Sometimes a fan is placed in one of the pipes to speed up the circulation of the air. The air-heating area of the furnace, of course, is separate from the firebox and chimney. A hot-air heating system heats a house rapidly but it also allows the temperature to fall rapidly when the fire dies down.

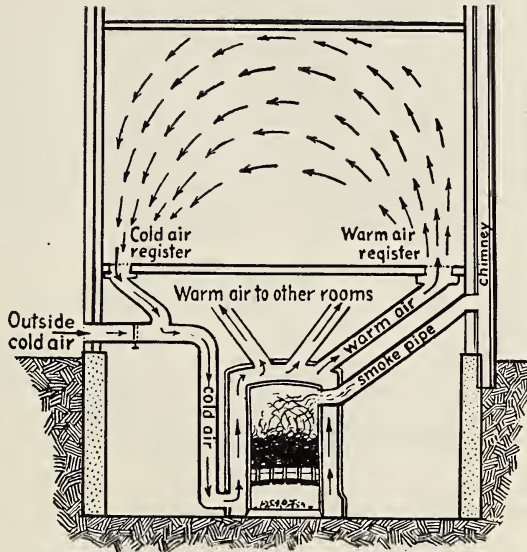


Fig. 136. Diagram showing the path of convection currents set up by a hot-air heating system.

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How a hot-water heating system works. A second type of heating system that operates on the basis of convection is the hot-water heating system shown in Figure 137. Such a system consists of a boiler, an expansion tank, pipes, and radiators. The boiler that

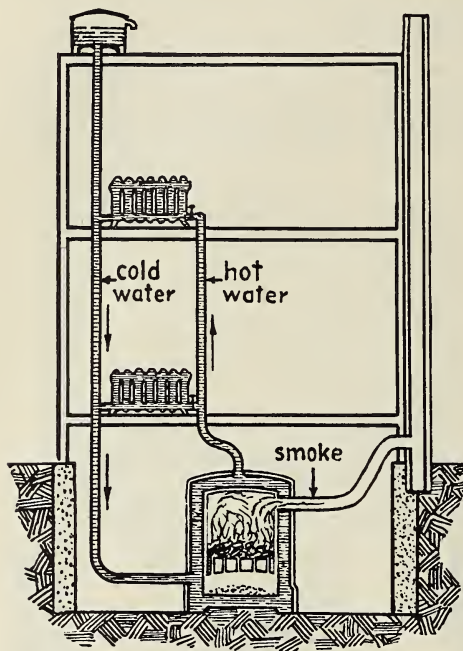


Fig. 137. Cross-section diagram of a house, showing how typical hot-water heating system operates.

heats the water is always situated beneath the expansion tank, which supplies water for the system and allows for the expansion of water when heated. In the drawing the boiler is situated in the basement and the expansion tank in the attic above the highest radiator. When the water in the boiler is heated, it becomes less dense than the cold water in the expansion tank, thus permitting cold water from the expansion tank to flow downward as indicated by the arrows. This flow of cold water into the boiler

forces the hot water from the boiler up through the pipes, as indicated by the arrow, to the radiators that heat the various rooms. As the water passes through the pipes and radiators, it loses some of its heat and hence becomes more dense than the water in the boiler. Therefore it flows through a connection and joins the water flowing from the expansion tank to the boiler. This circulation continues through boiler, pipes, and radiators as long as heat is supplied to the boiler.

Why does smoke go up the chimney? A motion of air is caused in a chimney by the heat from the fire warming the air, thus causing it to be less dense than the cooler air outside of the chimney.



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Here we see smoke pouring from the smokestacks of a factory. The smoke leaves the chimney because it is forced out by the cool, dense air entering the firebox from outside.

Cooler air enters the furnace through the draft holes in the front of the firebox and forces the warm, smoke-laden air up the chimney. In an open fireplace the smoke is carried up the chimney by the heavier air of the room. The higher the chimney or smokestack the better the draft, because the taller the chimney the greater the difference in weight between a volume of cold air on the outside and an equal volume of hot air or gases on the inside. A chimney "draws" especially well when a strong wind blows across the top of the structure, because the rapidly moving molecules of the wind drag along with them some of the molecules of the gases inside the chimney. This action permits the gases within the chimney to expand and become less dense, causing a greater difference of pressure between the outside air and the gases within the chimney. As a result of this difference in pressure the heavier air entering the firebox from outside forces upward the lighter air inside the chimney.

CONDUCTION

How heat travels through solids. How does the heat that is carried to the radiator by the hot water get through the radiator? The explanation is fairly simple, for it is based on what we have already learned about the action of molecules in any substance that is heated. If one end of a piece of iron is held in a flame and the other end held by the hand, the end in the flame gets hot first. Gradually the iron becomes hot from one end to the other. Heat energy is transferred to the molecules of the iron that come in contact with the flame. The molecules increase their velocity and strike the adjoining molecules, causing them to move faster. This is continued until the molecules at the other end have been affected in the same way. The heat from the flame is thus conducted to the other end of the iron rod that is held by the hand. The process of transmitting heat energy through a body from molecule to molecule as is illustrated in the heating of the iron rod is called conduction. This is the method by which the heat within the radiator is transmitted to the outside of the radiator.

The hot-water system transmits heat by convection and by conduction. The heat from the fire in the furnace is carried to the radiators by the water convection. The radiator becomes hot by conduction of heat through the metal of the radiator. The air closely surrounding the radiator is heated and becomes lighter or less dense than the other air of the room. The heavier or cold air of the room pushes the warm or lighter air away from the radiator and in turn becomes warm. This process continues until all of the air becomes warm. As the air away from the radiator becomes chilled again, it becomes more dense and the above process is repeated. Convection carries heat from the flame to the radiator, conduction is used to get the heat from the inside to the outside of the radiator, and then convection causes all of the air of the room to become warm.

Good and poor conductors. Certain materials are better conductors of heat than other materials, probably because of the arrangement of molecules. Two simple demonstrations will show how rapidly

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a good conductor carries away heat. First, we light the gas from a Bunsen burner and hold a piece of fine-meshed wire gauze over the flame as illustrated in Figure 138. The flame does not appear above the gauze. The wire gauze conducts the heat away so rapidly that the gas that escapes above the wire does not receive enough heat to cause it to reach its kindling point. Second, we turn on the gas, hold the wire gauze above the escaping gas, and hold a lighted match above the gauze.

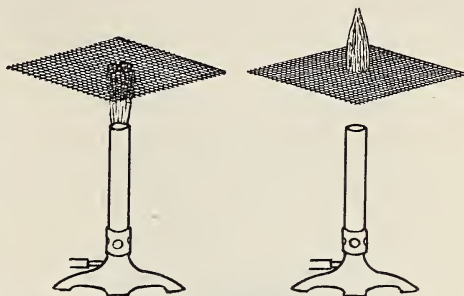


Fig. 138. Apparatus for experiment demonstrating conductivity in a piece of fine-meshed wire gauze.

The gas above the gauze ignites and burns, but there is no flame below the gauze. Again the gauze conducts the heat away so rapidly that the gas below does not reach its kindling point. Open-flame lamps used by miners have a wire gauze around the flame to prevent the heat from igniting any gas that may be in the mine. This lamp is known as the Davy lamp because Sir Humphrey Davy, an English scientist, invented it.

The best conductors of heat are metals, silver being the best conductor, copper second, aluminum third, and iron fourth. Liquids are better conductors than gases, but both are much poorer conductors than metals. Iron conducts heat about 100 times as readily as water, and water about 25 times as readily as air. Wool, fur, paper, and other substances of low density, or substances that contain large air spaces, are always poor conductors. Woolen clothes keep the body warm in winter because wool is a poor conductor and hence prevents the heat of the body from being carried away. The walls of houses are built in vertical layers with air spaces provided between the layers, or they are built with materials that already have numerous air spaces in them. Such construction keeps the inside of the house warmer in cold weather by preventing the heat from passing out, and cooler in hot weather by preventing the heat from coming in.

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Refrigerators are built much better today than they were a few years ago because manufacturers know more about the conductivity of materials. A good refrigerator remains cold inside because it is well insulated; that is, it has very poor heat-conducting materials between the inside and outside walls to prevent the heat from passing into the refrigerator. A fireless cooker, also, is made

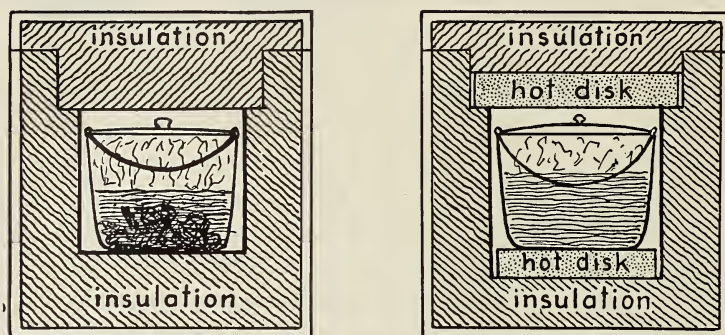


Fig. 139. Diagrams showing how fireless cookers are designed to hold the heat.

of materials that are very poor conductors of heat. This material prevents the heat on the inside of the cooker from getting out. If the dish of food is heated on a stove and then is placed in a fireless cooker, it continues to cook by means of the heat which it received from the stove. Sometimes heated disks of stone are placed in the cooker with the food to assist in the cooking process. Figure 139 illustrates two types of fireless cookers.

RADIATION

How does the heat from the sun reach to earth? It is known that the earth's atmosphere extends only a few hundred miles high at most and that above this is a vacuum. Heat cannot reach us from the sun by either convection or conduction because in both of these processes of transmission of heat there must be some substance by which it can be transmitted. Other examples of heat transmission through empty space are familiar to all of us. There is a high vacuum in a radio tube, yet the heat from the filament reaches the glass bulb and causes it to get warm. Likewise, heat

HOW HEAT IS TRANSFERRED

reaches the hand when held under a lighted electric-light bulb although in many cases there is a vacuum in the bulb. In order to explain how the heat from the sun and from other hot bodies is transmitted, scientists have imagined, and some believe they have proved, that there exists an elastic, weightless fluid that they call ether, which fills all space and transmits heat, light, X-rays, and radio energy by a process called radiation.

"Waves" in a vacuum. It is now generally thought that the energy radiated by the sun and other hot bodies travels as a wave. This energy is radiated or transmitted through the ether somewhat as the water by waves. Energy in the form of radiation travels at the speed of light, which is approximately 186,000 miles per second in empty space. It travels through a vacuum or through the ether.

We get our heat from the sun because the molecules or parts of the molecules of the sun are vibrating and release radiant energy somewhat as a vibrating violin string sends out energy. This energy is transmitted by waves traveling through ether at the rate of 186,000 miles per second to the earth. The molecules of the earth or bodies on the earth absorb the energy from the heat waves and move faster. Thus the heat of the sun is transmitted to the earth by radiation.

When heat is being radiated to your body by a hot object and you hold a book or paper between the object and your body, the heat waves are cut off. This fact shows that heat waves travel in straight lines. When a small cloud gets between you and the sun, the waves are cut off and do not reach you, for they travel in straight lines and cannot go around the cloud.

ANSWER THESE QUESTIONS

1. What three methods bring about a transfer of heat?
2. How does a hot-air heating system work? How does a hot-water heating system work? What are the essential parts of both these systems?
3. Why does a chimney "draw"? On what kind of day does it draw best?

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4. What is meant by good conductors of heat? What is meant by poor conductors?
5. How does heat come to the earth from the sun? How fast does the heat travel?
6. What is meant by ether? What reason is there to believe that heat is transmitted by waves?

AREA SIX

What Are Good Absorbers, Radiators, and Reflectors of Heat?

Perhaps it has never occurred to you that the color of horses makes a difference in how much they suffer from the heat on a hot summer day. Every farmer and every teamster knows, however, that black horses sweat more readily than white horses and consequently must be driven more cautiously. The reason for this will be explained on the following pages.

The white horse in the foreground of this picture can do work on a hot summer day with much less discomfort than the black horses. The black horses absorb more heat energy.

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ABSORBERS, RADIATORS, AND REFLECTORS

Dark-colored materials are good absorbers of heat energy. We know from experience that dark-colored clothes are warmer than light-colored clothes of the same material. We can easily demonstrate this fact in the winter when snow is on the ground and the sun is shining. We place two pieces of the same kind of material, one black and one white, on the snow. Soon the snow beneath the black cloth begins to melt from the heat absorbed by the black-colored material. The snow beneath the other cloth does not melt because the white-colored material does not absorb much heat. We can show again the absorbing qualities of black by using two tin cans, one blackened and the other unpainted and highly polished. We fill both cans with water and place them in the sun. The water in the black can becomes warm more quickly because the black surface absorbs radiant heat more rapidly, and of course imparts more heat to the water in the can. From the above and similar experiments, it is seen that black or dark objects absorb radiant heat energy more rapidly than light-colored or polished objects. This is shown by a radiometer, which is made of four vanes mounted so that they can turn in a partial vacuum tube. One side of each vane is blackened and the other side is polished. When exposed to the sun or other source of radiation, the blackened sides absorb more heat than the polished sides absorb. The rarefied air next to the blackened surfaces expands more than the air close to the polished surfaces. A greater force is exerted upon the blackened surfaces than upon the polished surfaces, causing the vanes to turn.

Dark-colored materials are good radiators of heat energy. If the two tin cans mentioned above are filled with hot water and placed in a cool room, the can with the blackened surface will have a lower temperature after a period of time than the one with the polished surface. This indicates that a dark surface also radiates heat more quickly than a polished surface. The heat from the water is conducted away more rapidly from the black can than from the polished one. On this account, then, the surfaces of radiators in homes should be dark and not polished. The inside of

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a thermos bottle, on the other hand, is silvered so that it does not radiate heat from the hot liquid which is placed in it. Neither does it absorb heat from the outside and transmit it to a cold liquid that is placed in it. A good thermos bottle consists of a glass double-walled container with a vacuum between the walls, the inside wall being silvered. Little heat gets into the liquid that is in the inner vessel and little gets out because:

(1) There is no matter between the two walls; therefore conduction cannot take place.

(2) There is neither air nor a liquid between the walls; therefore convection cannot take place.

(3) There *is* ether between the walls, which permits radiation; but since the inner wall is polished, it neither absorbs nor radiates heat rapidly.

A polished surface is a good reflector of heat energy. The reflector of an electric heater is polished so that it will reflect the heat into the room that is to be warmed. The inside of the thermos bottle, because of its polished surface, reflects the heat from a hot liquid back into the contents of the bottle; it does not absorb or radiate the heat. A smooth, bright surface is a good reflector, a poor absorber, and a poor radiator of heat. A blackened surface is a poor reflector, a good absorber, and a good radiator of heat.

ANSWER THESE QUESTIONS

1. What force produces the convection current in a hot-air heating system?
2. Why does hot water rise in a hot-water heating system?
3. Which of the following substances are good conductors and which are poor conductors: wool, soft wood, steel, water, air, silver?
4. How does a refrigerator operate to keep foods cool and a fireless cooker operate to keep foods hot?
5. How does radiation of heat differ from conduction and convection?
6. What kinds of materials absorb heat? What kinds reflect heat? What kinds radiate heat?

AREA SEVEN

How Does the Study of Meteorology Aid an Airplane Pilot?

Mark Twain once said, "Everybody talks about the weather, but nobody does anything about it." This statement may have been true in Mark Twain's time, but had he lived today, in the age of the airplane, he would have found a far different picture. Aviation is dependent upon weather, and every pilot must have a complete knowledge of weather in order to operate his airplane successfully. The science that deals with weather is called meteorology; the scientists who study it are known as meteorologists.

Weather conditions with which the pilot is concerned. When we say that the pilot is concerned with weather, we mean that he is concerned with the separate factors that help to make up weather, such as air pressure, temperature, humidity, and air currents, or wind. He is concerned with air pressure because air pressure enables him to predict fair and stormy weather. When the barometer is low, for instance, he knows that he may encounter clouds and precipitation. Of course, he must constantly interpret barometric readings in the light of elevation, for air pressure, as we have learned, decreases with altitude. The normal pressure at sea level at 0° Centigrade or 32° Fahrenheit is 29.92 inches or 76 centimeters of mercury, but at higher airports and at higher levels of flying it is considerably less. Besides using air pressure to predict fair and stormy weather, the pilot uses air pressure to help him locate air masses, or large blocks of air with fairly uniform conditions of density, temperature, moisture, and air currents. Primarily, as we shall find later, he is concerned with fronts, or the regions where two air masses meet.

The pilot is concerned with temperature because temperature, like air pressure, enables him to predict fair and stormy weather. When the relative humidity is high, he knows that a fall in temperature may cause precipitation. The temperature also enables him to judge the probable effects of heat and cold upon

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the working parts of his airplane. Especially must he watch for overheating of the motors and for the freezing of ice upon the airfoils. The temperature that he takes into account is free-air temperature, or the temperature indicated by a thermometer that is placed in a well-ventilated shelter and shielded from the direct rays of the sun.

The pilot is concerned with humidity because humidity indicates the condition of the atmosphere with reference to moisture. When the humidity is high, he realizes that he may have difficulty with visibility. In the case of fog or a heavy rain or snowfall the region of poor visibility may begin at the ground level, but in the case of clouds it may be several thousand feet high. The level at which poor visibility begins is known as the ceiling. If precipitation occurs, it may take the form of dew or rain at high temperatures, and frost, sleet, hail, or snow at low temperatures.

The pilot is concerned with air currents because he must consider the direction and the velocity of wind in taking off and landing and in maintaining the necessary direction in flight. Whenever we mention the direction of a wind, we refer to the direction from which it blows, a southwest wind being a wind that blows from the southwest. The pilot also depends upon the direction and velocity of wind to help him predict the approach of storms. In many parts of the country a storm is often preceded by a strong westerly wind. Frequently, too, a cold northerly wind chills the air and causes precipitation.

One interesting fact about the pilot in relation to weather is that he is concerned not only with weather at the ground level but with weather several miles high. Ordinarily the atmosphere is said to consist of three regions or layers; namely, the troposphere, the stratosphere, and the ionosphere, the first two of which greatly affect the pilot in his work. The troposphere is the region of atmosphere next to earth that extends upward about six miles at the poles and eleven miles at the equator, or an average of about 45,000 feet. This region, which is affected by surface weather conditions, is a region of decreasing density and temperature, the lowest temperature in the upper limits being about -67° Fahren-

METEOROLOGY AND THE AIRPLANE PILOT

heit. It is also a region of variable winds because the air is affected by ordinary surface conditions. The stratosphere, which extends upward from the troposphere to about 60 miles from the surface of the earth, is a region of decreasing density and uniform temperature, the temperature being about -67° Fahrenheit. It is also a region of stratified air currents, or winds produced by the rotation of the earth, the ordinary surface winds being confined to the troposphere. The ionosphere which is the highest level of atmosphere, extends upward from the stratosphere to about 500 miles from the surface of the earth.

METEOROLOGICAL ELEMENTS

The United States Weather Bureau. The chief agency that gathers data on weather for use in aviation is the United States Weather Bureau. This agency maintains about eight hundred stations throughout the United States and possessions for observing weather conditions. About five hundred of these stations are situated along airlines and the remainder in locations required for a complete coverage. Besides the reports from the established stations, the Weather Bureau also receives reports regularly from many ships at sea. The observations are made three times daily; namely, at 7:30 A.M., 11:30 A.M., and 1:30 P.M. Eastern Standard Time. The data are relayed by radio, telephone, and telegraph to certain designated places where they are analyzed by trained meteorologists. From such analysis the meteorologists draw conclusions concerning the kinds of weather to be expected within the immediate future. For instance, they notice the movement of highs and lows across the country and predict whether regions will have clear or stormy weather. This information is relayed by the Weather Bureau to airports where it is carefully studied by both ground crews and pilots.

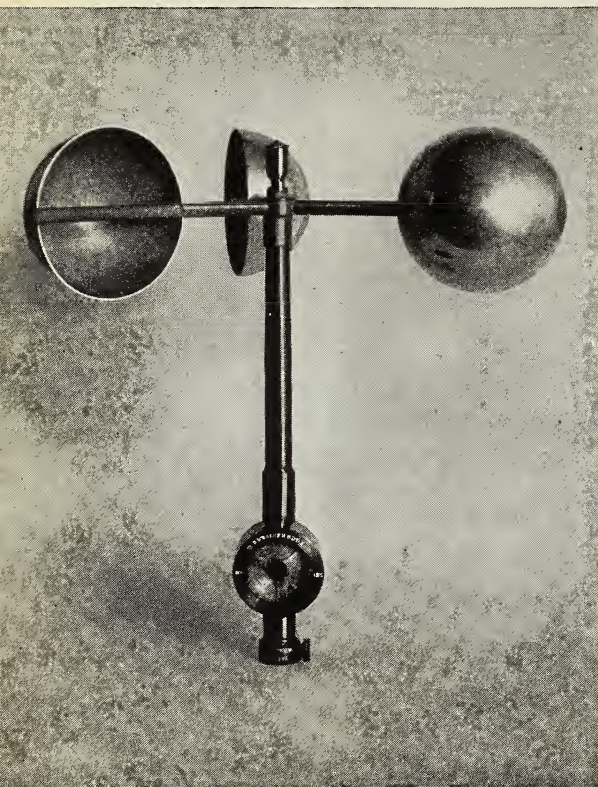
Gathering data at the ground level. In measuring air pressure, meteorologists commonly use a mercurial or an aneroid barometer. In measuring temperature they use either a Centigrade or a Fahrenheit thermometer. In measuring humidity they use a

THE DANCE OF THE MOLECULES

hygrometer, frequently of the type known as the hygrodeik, which registers the humidity direct. In measuring precipitation caused by rain they catch the rain in a can with a funnel-shaped top and find the height in inches of the water in the can. Usually the funnel-shaped top catches ten times the quantity of water that represents the true rainfall, and consequently they divide the height of the water by ten. In measuring precipitation in the form of snow they collect the snow as they collect rain, but they melt the snow before calculating the height. In determining the direction of wind they use a weather vane or a wind sock, which is a funnel-shaped cloth attached to a staff. In determining the velocity of wind they use an anemometer, of which there are several forms. One form consists of cups that rotate on horizontal axes and move a pointer on a dial calibrated to show miles per hour. Another form consists of two tubes one of which receives the full current of air and the other of which has holes along its sides and hence receives static air. The dial of this anemometer is also calibrated to show miles per hour.

As the cups on this anemometer revolve they indicate the velocity of the wind.

U. S. Weather Bureau



Getting data from high altitudes.

In gathering data from high altitudes meteorologists use an instrument known as a radiosonde, which they attach to a small balloon and send up to desired heights, sometimes as high as 75,000 feet. When the equipment reaches the desired height, the balloon bursts and the radiosonde descends by means of a parachute. The name and address of the meteorologist are attached to the radiosonde so that any finder may return it to the proper source. The radiosonde itself consists of a small radio

transmitter which is sensitive to such environmental conditions as pressure, temperature, and humidity. The transmitter under the effects of these conditions gives off signals that are picked up by a radio receiving set on the ground. The receiving set analyzes the signals in terms of pressure changes, temperature changes, and humidity changes. In addition to these data, it records all the changes upon a rotating cylinder.

In determining the direction and velocity of winds at high altitudes, meteorologists release small balloons filled with gas that causes the balloons to rise at known rates. They follow the ascent of each balloon carefully

with an instrument known as a theodolite, which records at one-minute intervals the angle of elevation and the angle from a northerly direction. From these directions and the known rate of ascent of the balloon, they readily calculate the direction and velocity of the wind.

In determining the height of a ceiling during the day, meteorologists release small balloons of known velocity in ascent and measure the time required for the balloons to reach the clouds. During the night they determine the height by throwing beams of light upon the undersurface of the clouds and calculating the distance by the angle of inclination.

Examining the clouds. One of the most interesting phases of the work of meteorologists is their study of clouds, for clouds enable them to make many predictions concerning weather. A cloud is



U. S. Weather Bureau

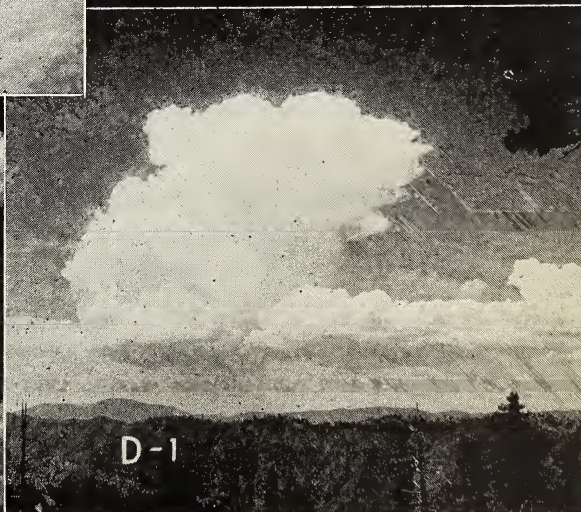
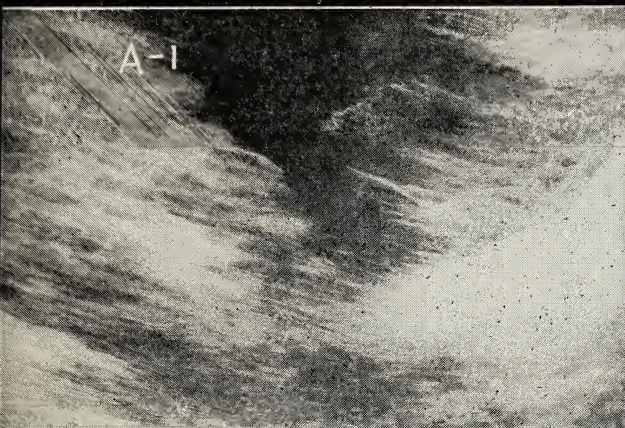
The radiosonde, carried into the air by a balloon, emits radio signals indicating various conditions of the atmosphere.

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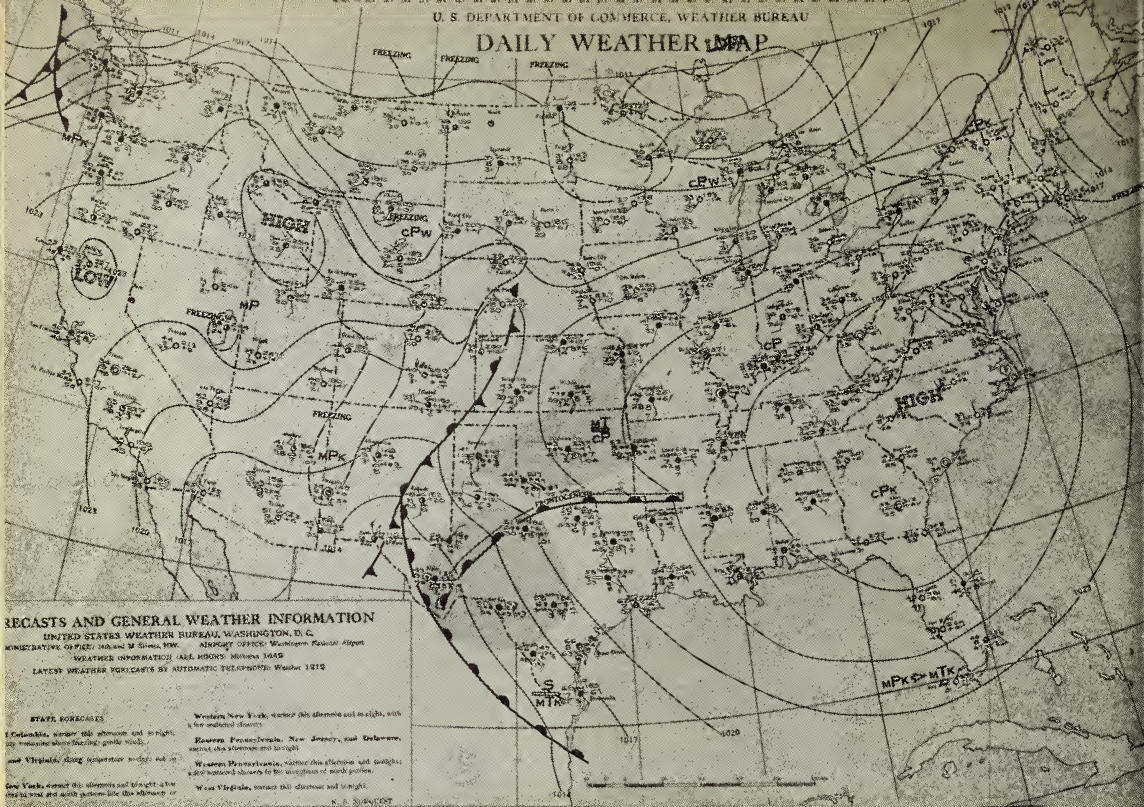
merely a block of atmosphere in which moisture has condensed to the extent that the vapor becomes visible. Such condensation takes place when the temperature falls to the saturation point or dew point. Clouds are of many different types, some of which are associated with one kind of weather and some with another, even with clear weather. All the types have special names, some of the more important of which are listed in the following table. Beside the name of each type is an index of its height, its chief characteristics, and its relation to the weather. The illustrations of clouds shown on the opposite page are identified by the designations assigned them in the following table.

CLASSIFICATION AND DESCRIPTION OF CLOUDS

FAMILY	TYPES OF CLOUDS	ALTITUDE OF BASE	CHARACTERISTICS AND WEATHER CONDITIONS
A. High clouds.....	1. Cirrus.....	32,000 feet..	Thin, white, silky clouds, common in winter. Clear weather.
	2. Cirro-cumulus...	22,000 feet..	Thin, cotton-like clouds. Fair weather.
	3. Cirro-stratus....	28,000 feet..	Thin, white, veil-like clouds through which the sun and moon shine, but which may cause halos. Rain.
B. Middle clouds.....	1. Alto-cumulus....	15,000 feet..	White woolly clouds. Advancing storm, increasing winds.
	2. Alto-stratus.....	17,000 feet..	Gray or bluish clouds, like cirro-stratus but without the halo. General rain.
C. Low clouds.....	1. Strato-cumulus..	6000 feet....	Huge gray clouds with dark spots, common in winter. Wind.
	2. Nimbo-stratus...	3000 feet....	Low, dark-gray clouds, fairly uniform. Rain or snow.
	3. Stratus.....	2000 feet....	Low, foglike clouds. Light drizzle or rain.
D. Vertical clouds.....	1. Cumulus.....	4000 feet....	White, dome-shaped clouds. Wind in vertical currents.
	2. Cumulo-nimbus.	3000 feet....	Heavy, irregular clouds extending upward from bases like mountains. Thunderstorms accompanied by turbulent wind, rain, hail, or snow.



DAILY WEATHER MAP



Above is shown one of the daily weather maps issued by the United States Weather Bureau. The map indicates areas of precipitation, high and low pressure, and storm and enables us to make predictions as well as to know conditions when the map was made. Maps for several days show the rate of movement of these areas.

Making weather maps. When the meteorologists in the United States Weather Bureau have collected the necessary data, they make maps, as shown in the illustration above, indicating weather conditions throughout the country for any particular day. In order to read these maps intelligently, a person must understand the meaning of certain symbols which are clearly defined in a key at the bottom of each map. Certain lines, known as isobars, for instance, pass through places having the same barometric pressure. Other lines, called isotherms, pass through places having a temperature of 0° Fahrenheit (if any) and freezing or 32° Fahrenheit. Still other lines with accompanying symbols show the location and nature of air fronts, or the meeting places of air masses. Besides these symbols others show degrees of cloudiness, precipi-

tation, wind direction, and the like. A shaded area on a map, for example, indicates continuous precipitation, and other symbols indicate intermittent and drizzling precipitation. Most of the smaller symbols are arranged in groups, each group indicating the conditions at a local weather bureau.

What causes winds? Winds require special consideration because they are closely associated with other phases of weather. Thus a wind frequently accompanies a rainfall, being caused by some of the same factors as the rainfall or helping to bring the rainfall about. Among the chief causes of winds are pressure, temperature, force of gravity, and rotation of the earth.

Differences in atmospheric pressure cause winds when air tends to move from regions of high pressure to regions of low pressure. The air tends to move in such directions as will equalize the pressure. An equalized condition never exists, because certain other factors tend to modify the pressure.

Differences in temperature cause winds because warm air is less dense than cold air and tends to rise, whereas cold air tends to settle. Cold air tends to move from the colder regions of the earth to the warmer regions, and warm air from the warmer regions to the colder regions. Thus winds tend to equalize the temperature just as they tend to equalize the pressure.

The force of gravity causes winds because it pulls the air toward the surface of the earth. This force explains why air is most dense near the surface of the earth and decreases in density upward from the surface. Any factor that disturbs the relative density of the air either at ground level or high above the surface tends to cause air currents or winds.

The rotation of the earth causes winds because the air rotates with the earth. The centrifugal force set up by the rotating of the earth tends to pull the air away from the earth. Opposed to this force is the force of gravity, which tends to pull the air toward the earth. The centrifugal force is greatest at the equator and decreases from the equator northward and southward. As the earth turns from west to east, the centrifugal force causes

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the air to lag or to move westward in relation to the earth. This deflection is greatest at the equator and gradually decreases toward the poles.

Trade winds. In general, the temperature at the surface of the earth decreases from the equator to the poles. This difference in temperature causes the cold air from the north and the cold air from the south to move along the surface toward the equator and to push the lighter warm air upward out of the way. As the warm air rises, it becomes cooler and cooler and finally moves back toward the poles. Thus along the surface of the earth the air moves from the poles toward the equator, and in higher regions in the opposite direction. Near the equator where the effects of rotation are greatest, the currents of air are deflected westward; hence at the surface the winds directly north of the equator

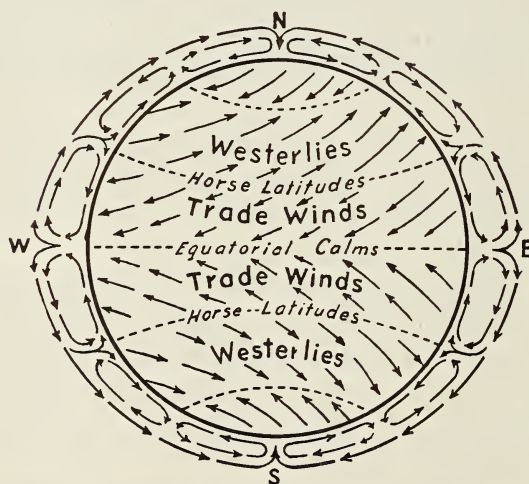


Fig. 140. Diagram showing principal wind belts of the world.

blow to the southwest and the winds directly south of the equator blow to the northwest, as shown in Figure 140. The winds that blow in these directions near the equator are known as trade winds, the term *trade* being used in its obsolete meaning of course or path. Along the equator where the trade winds meet and cause the warm air to rise is a windless region, the equatorial calms. North of the trade winds in the Northern Hemisphere and south of them in the Southern Hemisphere are other windless regions, the horse latitudes, where air descends because it has cooled in the higher regions and broken away from the air flowing back to the poles.

The westerlies. North of the horse latitudes in the Northern Hemisphere and south of the horse latitudes in the Southern Hemisphere air descends more gradually from the higher regions; hence this air tends to retain its northerly direction in the Northern Hemisphere and its southerly direction in the Southern Hemisphere. The rotation of the earth, however, deflects the air currents and causes the winds in the Northern Hemisphere to blow to the northeast and those in the Southern Hemisphere to blow to the southeast, as shown in Figure 140. Because these winds come from a generally westerly direction in both hemispheres, they are commonly called the westerlies. These winds are especially important, for they bring many changing conditions, including stormy weather, fair weather, hot waves, and cold waves. Since they move generally from west to east, they are helpful to meteorologists in predicting weather.

Land and sea breezes. Besides the foregoing classes of winds, there are others of lesser importance, such as land and sea breezes that occur where the land meets a large body of water. These breezes blow from the land toward the water in the morning and from the water toward the land in the evening. They may be explained by the fact that land heats more rapidly than water. Therefore in the morning the land is cooler than the water, and in the evening the water is cooler than the land. Land and sea breezes are important to fishermen because they drive fishing vessels out to sea in the morning and back to shore in the evening.

THE MEANING OF AIR MASSES

How air masses behave. Air masses are large blocks of air with the same general characteristics of temperature and moisture at each level. Air masses that are colder than the surface over which they move, are known as cold air masses, and those that are warmer than the surface over which they move, are known as warm air masses. The cold air masses originate in the polar regions and move toward the equator, and the warm air masses originate in the tropics and move toward the poles.

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As an air mass moves into a region, it usually brings a change in surface temperature and moisture conditions. For example, an air mass moving southward into central United States from the arctic regions of Canada in winter will bring cold, dry weather. As the southern edge or "front" of this cold air mass reaches a given place, temperatures will fall, clouds will form, and precipitation usually occurs. The clouds and precipitation result from the forcing upward of the warm air ahead of the cold front as the wedge of cold air moves along the surface, as shown in Figure 141A. After the cold front has passed by, the weather usually clears but remains cold. On the other hand, when a warm, moist air mass moves northward from the Gulf of Mexico, it brings with it higher temperatures and higher humidity conditions. As the moving air mass encounters colder surface air, the warm air tends to rise over the underlying cold air for some distance ahead of the surface front, as shown in Figure 141B. The cooling of the warm air as it rises produces condensation, clouds appear aloft, and precipitation usually occurs. The zone of precipitation accompanying a warm front is thus much wider than that which accompanies a cold front. In either case the amount and character of the precipitation that occurs will depend upon the temperature and moisture conditions which exist at the time.

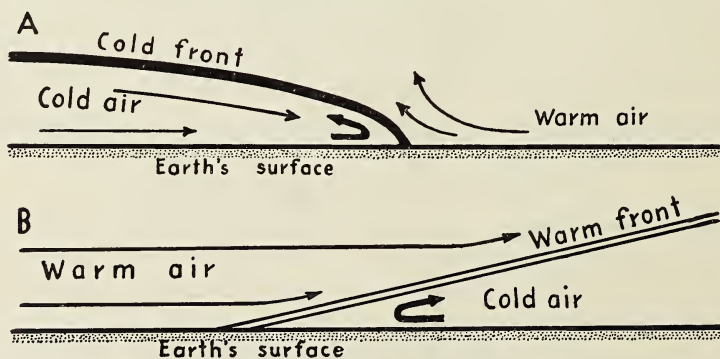


Fig. 141. Behavior of air along moving cold and warm fronts.

The importance of fronts. As we have seen, the advancing edge of a cold air mass is known as a cold front, since cold air replaces

warm air along the surface. Likewise, a warm front exists along the advancing boundary of a warm air mass, when warm air replaces colder air. A fast-moving cold front may produce extremely turbulent conditions as it forces the warm air ahead of it to rise rapidly. A long line of storms may develop along the cold front and thus present hazardous weather for flying. Airplane pilots always pay a great deal of attention to the cold fronts that are shown on their weather maps, especially in winter, when they may present a dangerous barrier of storms extending for hundreds of miles across a line of flight. Warm fronts are not nearly so dangerous except as they may produce low clouds which reduce visibility for take-offs and landings. Since moving fronts mean changing weather, however, they are always of great importance.

Stable and unstable air. Because of the many disturbing elements in the atmosphere, pilots frequently refer to the air as stable or unstable. Stable air, as its name indicates, is relatively quiet air, which decreases gradually in density upward from the surface of the earth. Unstable air, on the other hand, is air that is more or less turbulent, because of the various conditions already explained. The air within an air mass is usually stable because of the uniform conditions that prevail, but the air of fronts is usually more or less unstable.

Atmospheric waves. Waves are formed when water and the air above it have their adjoining surfaces disturbed by some accelerating force such as a breeze. In much the same manner air waves are formed along the sloping boundary between cold and warm air masses of different densities. A trough of rapidly moving cold air pushes against the warm air ahead of it and creates an atmospheric disturbance, or cyclonic storm. At the crest of the wave there develops a low-pressure center around which the near-by air tends to rotate or whirl. The entire cyclonic storm, with its warm and cold fronts, precipitation zones, and shifting winds, moves from west to east with the prevailing westerlies.

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One of these storms is shown just entering the northwest corner of the United States in the weather map on page 362. Weather forecasts for several days ahead will be based upon the known characteristics of this eastward-moving storm and its predicted path. Both meteorologists and pilots keep track of such storms from day to day by means of daily weather maps, and even from hour to hour by means of radio reports. The interpretation of weather maps and weather reports constitutes a basic phase of every pilot's scientific training. Farmers, shippers, travelers, and many others whose daily activities are affected by changes in weather, also need to understand the general principles of meteorology.

ANSWER THESE QUESTIONS

1. What is meant by meteorology? Who is a meteorologist?
2. How is a pilot concerned with weather conditions?
3. What are the three regions, or layers, of atmosphere? With which of these regions is the pilot concerned?
4. What stations does the United States Weather Bureau maintain for gathering data on weather? At what times of day are the data collected?
5. What instruments are used in gathering data on surface weather conditions? in gathering data on weather conditions at high altitudes?
6. What is a cloud? How are clouds classified? Which clouds would you say are the most important?
7. What is a weather map? What are some of the important symbols on the map?
8. What are the chief causes of winds? What does each cause contribute?
9. What are trade winds? In what direction do trade winds blow in the Northern Hemisphere? in the Southern Hemisphere?
10. What are the westerlies? How are these winds produced?
11. How are land and sea breezes produced?
12. What are air masses? Why are air masses important?
13. What are air fronts? Explain the differences between a cold front and a warm front as to air behavior and weather changes.
14. What is the difference between stable and unstable air?
15. What are atmospheric waves? Why are they important?

James Prescott Joule
(1818-1889)

Joule, an outstanding English physicist, was educated by private tutors. He was given special instruction in the physical sciences which developed his interest in physics and chemistry at an early age. He made many notable contributions to our understanding of heat. Among these is his formulation of a method for determining mathematically the heat equivalent of electrical energy.

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AREA EIGHT

What Is the Relation between Heat and Work?

Everyone knows that there is a close relation between heat and work. In some cases, as in the case of refrigeration, we wish to counteract the effects of heat. In other cases, as in the case of the steam engine, we must utilize heat. The following pages will explain how heat affects the operation of certain machines.

Equivalent heat-energy units. The engineer and the scientist are interested in knowing how many units of one kind of energy it takes to make one unit of another. They wish to know how many mechanical-energy units, measured in foot-pounds, ergs, or gram-meters, are required to make one heat unit, measured in calories or B.t.u. The first person to study the relation between mechanical energy and heat energy was Benjamin Thompson. This scientist worked on the problem in 1798 while boring cannon.

The next person to study the relation between mechanical energy and heat energy was James Prescott Joule, an English physicist. Joule's apparatus consisted of a weight attached to a pulley that turned a shaft and rotated paddles in a churn as shown in Figure 142. Filling the churn with water, attaching a known

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weight, and winding up the crank, he caused the apparatus to paddle water in the churn. Then he measured the distance through which the weight fell and determined how many gram-

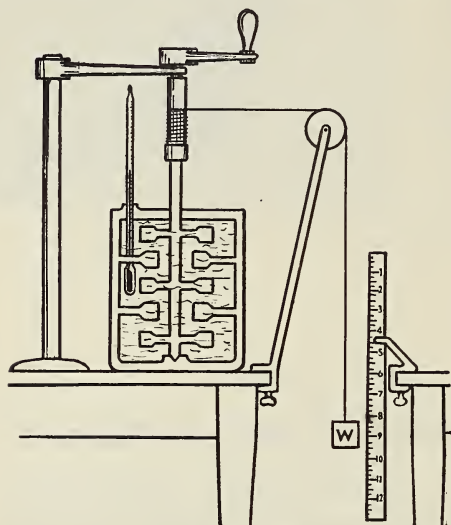


Fig. 142. Apparatus used by Joule for measuring the relation of heat and mechanical energy.

meters or foot-pounds of work were done in paddling the water. Finally he took the temperature of the water and found how many heat units had been added as a result of the paddling. Checking his results, he found that 427 gram-meters of work are required to increase the temperature of water one calorie and that 778 foot-pounds of work equal one B.t.u.

So Joule's experiment, in which he found the mechanical equivalent of heat, helped to strengthen the theory of the conservation of energy;

namely, that *energy can neither be created nor destroyed. It can be transformed from one form to another with neither loss nor increase in the units of energy transformed.*

The physics of the universe. This law is true for all energy changes that have been observed upon the earth, but we are not sure that it holds true for all energy changes in the universe. Scientists can only speculate as to how far the conservation of energy theory applies to the universe. Some hold to the theory that the energy in the universe is "running down." According to this belief, heat energy that is lost on the earth passes to other parts of the universe and tends to equalize the temperature of the universe. Thus there will come a time when heat will be uniformly distributed and everything will become cold and motionless. Other scientists hold to the theory of transformation, or belief that

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the universe is "winding up." According to this belief, heat energy that is lost on the earth is transformed into some form of matter that produces radiant energy, or light. The sun is referred to as an illustration of the fact that matter produces radiant energy. Both theories are speculative, but one day scientists may be able to prove or disprove one or the other or substitute a theory that is better.

REFRIGERATION

Refrigeration in modern life. One of the chief ways in which man relates heat to work is in the field of refrigeration. Great progress has been made in refrigeration within recent years, with the result that many foods that once went to waste can now be preserved. Such preservation is of importance, not only to merchants who handle food products and to housewives who prepare foods for the table, but also to persons who transport foods from one place to another. Today foods that once could be transported only short distances can be transported safely across the country and even from other parts of the world.

Refrigeration is based upon the principle that heat passes from one body to another provided the first body has a higher temperature than the second. Thus in a refrigerator heat passes from the objects in the food chamber to the near-by coils and gradually reduces the temperature of the food chamber. The coils remain cold because they are filled with liquids that evaporate and take on heat in the process. These liquids absorb heat when changing to gases because energy is used in pulling the molecules apart.

Artificial refrigeration by the compression method. The compression type of refrigerator consists of a compression pump operated by an electric motor. This pump compresses a gas, such as sulfur dioxide or ammonia, in coils exposed to the air or surrounded by water. When the gas is compressed, it turns into liquid and takes on heat but cools again as it flows through the coils. The liquid, which has been made from the gas, now flows into other coils in the cooling part of the refrigerator. Here the liquid expands and

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turns into a gas, and its temperature falls, causing it to take in heat from objects near the coils. Then it passes back to the first coils, where it is compressed again and converted into a liquid. Provision is made also in the refrigerator for releasing the heat absorbed from the food chamber to the atmosphere outside the refrigerator, where it is dispersed.

Artificial refrigeration by the absorption and cooling method. The absorption and cooling type of refrigerator, often called the gas refrigerator, consists of a circuit of tubes filled with a solution of ammonia, water, and hydrogen gas. The solution passes over a flame, usually a gas flame, that causes the solution to liberate ammonia gas. The ammonia gas passes through a series of pipes exposed to the air where it condenses into a liquid. The liquid then passes into coils that contain the hydrogen gas in the cooling part of the refrigerator. Here it evaporates, and its temperature

This picture shows a housewife removing articles of food from a modern electric refrigerator. Such a refrigerator keeps food cool by compression of gas into a liquid.

Ewing Galloway



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falls, causing it to take in heat from objects near the coils. The mixture of gas then flows through a section that contains water, where the ammonia gas unites with the water to form the solution of ammonia again. The hydrogen that is set free returns through a pipe to the section from which it started. Provision is made in the gas refrigerator, as in the compression type, for releasing the heat absorbed from the food chamber to the atmosphere outside the refrigerator where it is dispersed.

Quick freezing. At the present time much use is being made of the methods of quick freezing of vegetables, fruits, and meats. If the above-named foods are frozen quickly and kept in places that are below freezing, they are almost in the same condition when used as when they were frozen. This enables us to have "fresh" foods when they are out of season. There are several methods of quick freezing, some of which are: (1) freezing by immersion in brine, (2) freezing by indirect contact with the refrigerant, and (3) freezing by blasts of cold air. After the food is quickly frozen, it must be kept frozen. This necessitates delivery conveyances that can keep temperatures below freezing. After the frozen foods are delivered to the retail stores, they must be kept in containers at a temperature below freezing.

THE STEAM ENGINE

From heat to steam to mechanical energy. Another type of device in which man relates heat to work is the steam engine. Even the ancient Greeks and Romans constructed devices for translating heat into mechanical energy, but such devices were only toys. Not until man knew more about the principles of heat was he able to build a practical working device. The first person to succeed in this venture, as we have already indicated, was James Watt, who built the steam engine. The advent of this engine marked the beginning of an industrial era that has completely changed methods of production and transportation in the world. As a result of these changes, the ways of living have almost completely changed in many parts of the world.

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The essential parts of the steam engine, as shown in Figure 143, are the boiler and the cylinder which includes the piston. The fire under the boiler heats the water and produces steam that passes to a steam chest. From the steam chest the steam passes

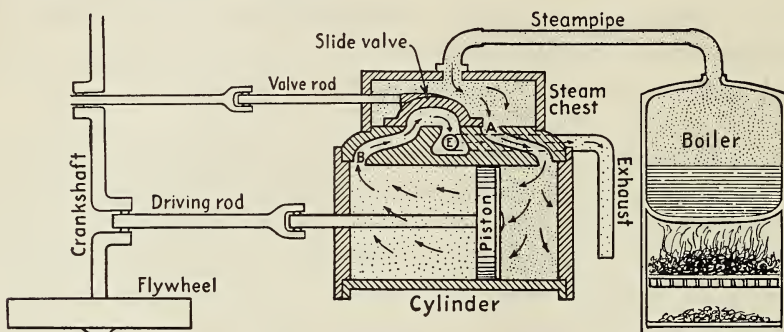


Fig. 143. The drawing above is a cross section of a steam engine showing the essential working parts. The steam passes from the boiler to the steam chest and from there to the cylinder where it exerts force upon the piston which moves the driving rod.

through an opening into the cylinder. In the position illustrated in the drawing, the steam is passing through opening *A* and pushing the piston to the left, as indicated by the arrows. When the piston reaches the left end of the cylinder, steam enters through opening *B* and forces the piston to the right. Attached to the piston is a rod, known as a driving rod, that rotates a crankshaft. The crankshaft in turn provides power for running machinery and in many engines rotates a flywheel as shown in the drawing. The flywheel helps to regulate the turning of the crankshaft, or to bring about uniform motion.

A very important part of the steam engine is the slide valve that regulates the flow of steam to the cylinder. This valve is operated by a rod known as the valve rod, which is attached to the crankshaft. When the piston moves to the left, the slide valve moves to the right and vice versa, thus alternately opening and closing openings *A* and *B* from the steam chest into the cylinder. Passage *A* opens when the piston reaches the right end of the cylinder, and passage *B*, when the piston reaches the left end of

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the cylinder. The steam, after it has forced the piston from one end of the cylinder to the other, passes into an exhaust chamber or pipe indicated by *E*.

Steam engines are commonly divided into two classes, the high-pressure engine and the low-pressure engine. The high-pressure engine is one in which the spent steam escapes into the atmosphere. When the steam is forced from the cylinder by the movement of the piston, it sets up a resistance of one atmosphere, or 14.7 pounds per square inch, to the movement of the piston. Consequently, the pressure in the steam chest must be kept relatively high to offset the resistance. The low-pressure engine is one in which the spent steam escapes into a condenser, where it meets a spray of cold water and turns into liquid, in which form it returns to the boiler. As the steam changes into liquid in the condenser, it creates a partial vacuum that practically eliminates the resistance to the piston in the cylinder. In the absence of resistance, the steam chest is kept at a relatively low pressure.

Efficiency of a steam engine. Much of the energy of the steam that passes into the cylinder of a steam engine goes out with the escaping steam. Scientists have proved by higher mathematics

that the efficiency of a steam engine $= \frac{T_1 - T_2}{T_1}$, where T_1 is the ab-

solute temperature at which the steam enters and T_2 is the absolute temperature at which the steam leaves the engine. This equation shows that the efficiency of a steam engine is in proportion to the difference between T_1 and T_2 . Engineers try so to construct engine units that the steam enters the cylinder at a high pressure, which carries along with it a high temperature, and leaves the cylinder at a low pressure, which means a low temperature. For example, if the steam enters the engine at 200° Centigrade or 473° (T_1) and leaves at 100° Centigrade or 373° (T_2),

then the efficiency of the engine is $\frac{473 - 373}{473} = \frac{100}{473} = 21$ per cent.

The efficiency of a good boiler is about 70 per cent; that is, about 70 per cent of the heat energy of the coal or fuel goes into

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the heat energy of the steam. If an engine has an efficiency of 21 per cent and the boiler has an efficiency of 70 per cent, then the two together have an efficiency of 70 per cent $\times$ 21 per cent = 14.7 per cent; that is, 14.7 per cent of the heat energy of the fuel is changed into mechanical energy.

Horsepower of an engine. The pressure of the steam upon the piston is always changing, but it can be found by the use of a steam-engine indicator. The indicator registers the average pressure for one stroke. The average difference of pressure on the two sides of the piston, which is called the mean effective pressure, can also be found. The area of the piston equals the square of the radius multiplied by π . If these two facts are known, the average force upon the piston for one stroke is found by multiplying the area of the piston by the mean effective pressure. Work equals force multiplied by distance; the work done in one stroke is therefore the product of the force and the length of the stroke. Since the steam drives the piston as it moves both ways, the amount of work for each revolution of the crankshaft is twice the product of the force upon the piston and the length of the stroke. The total work for one minute is twice the product of four quantities: the area of the piston, the mean effective pressure, the length of the stroke, and the number of strokes per minute. One horsepower is 33,000 foot-pounds per minute. The horsepower of the engine is the total work divided by 33,000. The formula for determining horsepower is as follows: horsepower $= \frac{2PLAN}{33,000}$, where P is the mean average pressure, L the length of the stroke in feet, A the area of the piston in square inches, N the revolutions per minute (r.p.m.).

Example. A steam engine has a piston 8 inches in diameter, a stroke of 16 inches, an r.p.m. of 150, and a mean average pressure of 100 pounds per square inch. Find the horsepower (HP.) of the engine.

$$\text{Solution. HP.} = \frac{(2)(100)(1\frac{1}{3})(\pi 4^2)(150)}{33,000} = 60.9 \text{ HP.}$$

The steam turbine. The latest and most efficient method of transforming heat energy into mechanical energy is by means of a steam turbine. Steam is driven at high velocity against a series of blades arranged around the circumference of a wheel, as shown in Figure 144. This wheel, known as a turbine wheel, turns under the force of steam much in the same manner as a windmill turns under the force of wind. As the wheel rotates it turns a shaft to which are attached pulleys or cogs. These pulleys or cogs in turn transmit power to machines for carrying on work. In order to utilize the full force of the steam, several turbine wheels or series of blades, sometimes as many as sixteen, are attached to the same shaft. Thus when the steam passes through the turbine it exerts force upon all the blades in the system. In designing a turbine care must be taken to control the direction of the steam, for when the steam strikes one series of blades it changes its course and hence may not strike the second series at the most efficient angle. To overcome this difficulty, engineers provide stationary blades which are attached to the jacket or covering of the turbine. These stationary blades are arranged in rows between the series of revolving blades, as shown in Figure 145. By observing the direction of arrows in the drawing we can see how the stationary

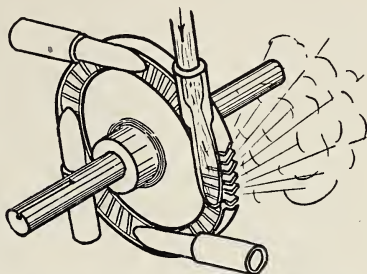


Fig. 144. How a steam turbine works.

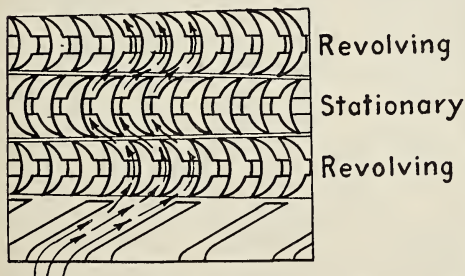


Fig. 145. Cross-section diagram of a steam turbine showing alternate revolving and stationary blades.

blades work with the movable blades. The steam flows smoothly from a series of revolving blades to a row of stationary blades and then on to the next series of revolving blades, striking all the blades at the correct angle in order to utilize the full force of the steam.

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THE INTERNAL-COMBUSTION ENGINE

Utilizing the force of explosion. A third type of device in which man relates heat to work is the internal-combustion engine, so named because combustion takes place inside the cylinder. This combustion has the same effect upon the piston that the explosion of powder has upon the projectile of a cannon. The piston, however, does not leave the cylinder as does the projectile of a cannon, because it is attached to the crankshaft. When the explosion occurs, the piston moves from one end of the cylinder to the other and turns the crankshaft.

The internal-combustion engine is most widely used as a source of power for automobiles and airplanes. All such engines are more or less complicated because various combinations of cylinders are attached to the crankshaft. Most automobile engines, for instance, have six or eight cylinders, and a few have twelve or sixteen cylinders attached to the crankshaft. When two or more cylinders are attached to the crankshaft, the explosions take place in succession and hence tend to equalize the power.

If we look at Figure 146, we can readily see how one of the cylinders of an internal-combustion engine works. The first drawing shows the position of the piston before the vaporized fuel enters the chamber. The second drawing shows the intake stroke

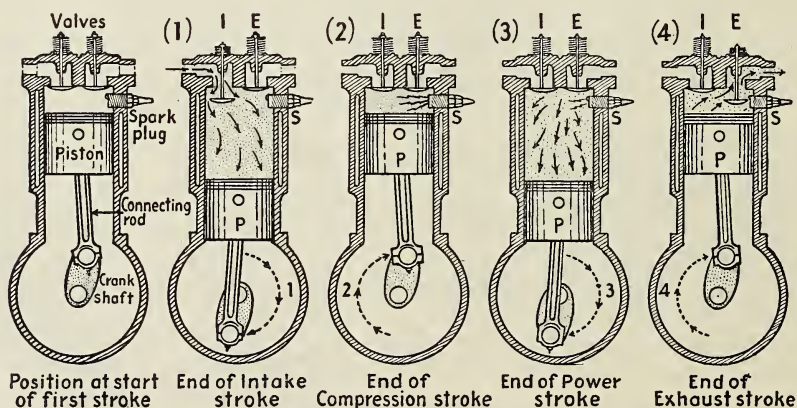
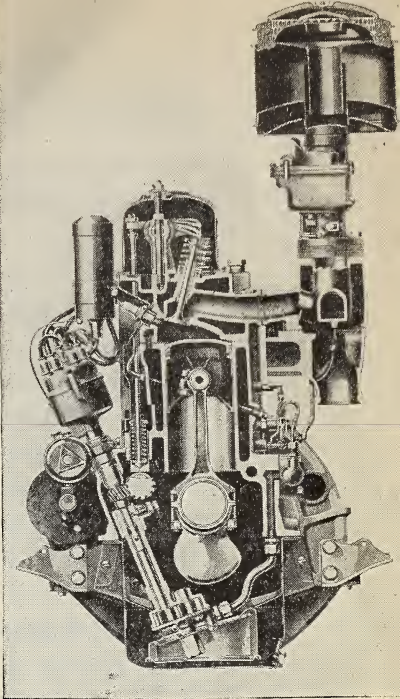
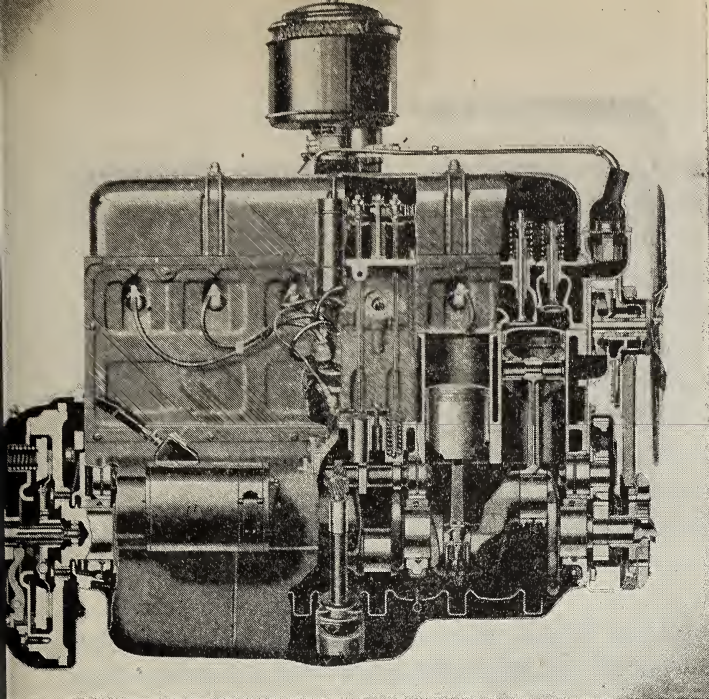


Fig. 146. Drawings showing the four successive steps in the operation of a cylinder.



Chevrolet Motor Co.

In addition to showing the working parts of a gasoline engine, this picture illustrates where the air is cleaned before it is mixed with the gas. The cylindrical-shaped part at the top is the air cleaner through which air passes before entering the carburetor.

of the piston, or the stroke caused when vaporized fuel enters intake valve *I* and fills the cylinder back of the piston. The third drawing shows the compression stroke, or the stroke when intake valve *I* closes and the piston compresses the vaporized fuel in the cylinder. The fourth drawing shows the power stroke, or the stroke when the spark causes the vaporized fuel to explode and force the piston through the cylinder. The fifth drawing shows the exhaust stroke, or the stroke when exhaust valve *E* opens and the piston forces the exhaust mixture from the cylinder. Thus for one completed operation the piston makes four strokes, two in each direction, only one of which provides power. The piston keeps on moving between the power strokes because a heavy flywheel is attached to the crankshaft. This flywheel gains power from the piston on the power stroke and gives back power for the other three strokes. Besides aiding the piston in this manner, the flywheel also helps to make the power uniform for

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running machinery. An engine that makes four strokes, as described above, and that is the type most commonly used, is known as a four-cycle engine.

One of the most important parts of the internal-combustion engine is the carburetor, which vaporizes the gasoline, or mixes the gasoline with air. As the air enters the carburetor, it creates a partial vacuum and hence produces a suction effect which causes the gasoline to flow from the tank. The vaporized fuel from the carburetor passes directly to each cylinder, where it is caused to explode by an electric spark. This spark is produced by an electric current that jumps across a short gap in a spark plug attached to the end of the cylinder.

The Diesel engine. The Diesel engine is now being employed for a variety of purposes. Diesel engines are used on submarines to propel them on the surface, charge the batteries, operate pressure pumps, and furnish all power in preparation for submerging. The Diesel engine operates on either the two-stroke or the four-stroke cycle. It differs from the conventional internal-combustion engine in its principle of ignition. In the conventional engine the ignition of the mixture of gas and air is accomplished by an electric spark generated and timed by the ignition system; the Diesel engine produces combustion from heat generated by very highly compressed air.

Instead of a mixture of air and fuel as in the conventional internal-combustion engine, pure air is introduced into the cylinders of a Diesel engine. Here the pure air is compressed into a much smaller space, the increased pressure causing a great increase in the temperature of the air. This highly compressed pure air in the Diesel cylinder reaches a temperature of over 1000° Fahrenheit, which is far above the ignition temperature of any fuel that is used. At this point highly atomized fuel is injected into the cylinder just before the piston gets to the top center on the stroke that compresses the air (compression stroke). When the fuel comes in contact with the high-temperature compressed air in the cylinder, ignition of the fuel takes place

THE RELATION BETWEEN HEAT AND WORK

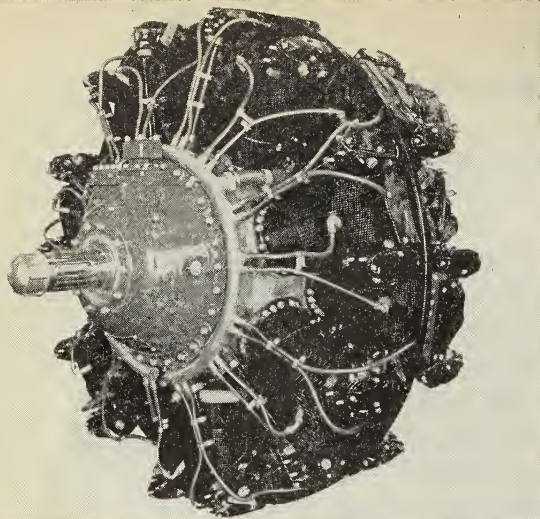
immediately and starts combustion that acts upon the piston and causes it to make the power stroke just as it does in the conventional internal-combustion engine.

In the place of the carburetor, or mixing device, that is used in the ordinary engine, the Diesel engine uses a fuel pump and a nozzle that injects atomized fuel directly into the cylinder for combustion at the desired time. The quantity of fuel injected regulates the amount of heat generated. The regulation of the quantity of fuel does not require the regulation of the quantity of air as is necessary in the ordinary engine. Since the temperature in the cylinder of a Diesel engine is high, liquid fuels that have a low volatility can be used.

Aircraft engines. The engines employed in aircraft are internal-combustion engines especially designed to produce great power in relation to their weight. So much has been accomplished in this direction that some engines deliver approximately one horsepower for each pound of weight. Another factor that is especially important in aircraft engines is compactness, for compactness enables them to reduce the resistance of the air. To aid in reducing resistance, most engines are streamlined with a small frontal area and sloping sides. Only internal-combustion engines can meet the requirements of lightness and compactness, for steam engines are relatively bulky and large.

Aircraft engines are divided into two classes on the basis of cooling systems; some are water-cooled and others air-cooled. The water-cooled engine has the advantages of dissipating heat readily and of being relatively easy to streamline for the purpose of reducing air resistance. It has the disadvantages of leaking, freezing at low temperatures, and adding to the weight of the aircraft. The air-cooled engine that is most commonly used has the advantages of eliminating leaking and freezing and of being light. It has the disadvantages of cooling less efficiently and of being more difficult to streamline.

On the basis of the arrangement of cylinders with respect to the crankcase, aircraft engines of the water-cooled type are often



Wright Aeronautical Corporation

Picture of engine shown in drawing 7.

divided into four classes as follows: the in-line type, the **V** type, the double-**V** type, and the **X** type as shown in drawings 1, 2, 3, and 4 in Figure 147. The cylinders in the in-line type are arranged in a single row in the crankcase; the cylinders in the **V** type are arranged in a double row in the crankcase; the cylinders in the double-**V** type are arranged in four banks resembling a fan in the crankcase; and in the **X** type

two cylinders are arranged on one side of the center line and two on the other. All these types use one crankshaft to drive the propeller except the double-**V** type, which uses two crankshafts.

On the basis of the arrangement of cylinders, aircraft engines of the air-cooled type are commonly divided into classes as follows: the in-line type, the opposed or flat type, the single-row radial type, and the double-row radial type, shown in drawings 1, 5, 6, and 7 in Figure 147. The cylinders in the in-line type of air-

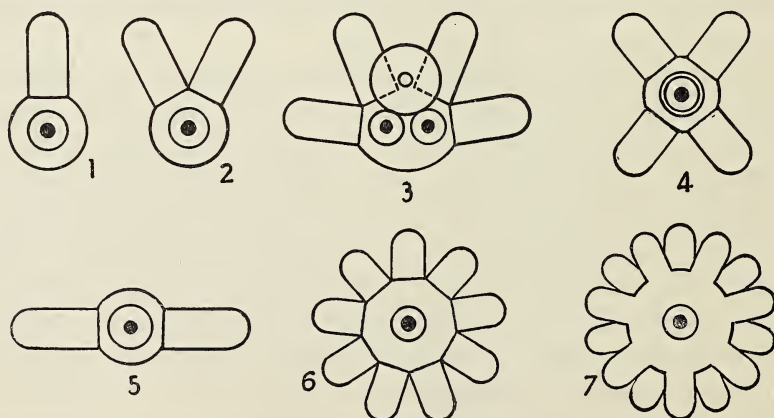


Fig. 147. Diagrams showing various arrangements of cylinders around the crankshafts of both water-cooled and air-cooled airplane engines as described in the text.

cooled engine are arranged the same as in the water-cooled type already described. The cylinders in the opposed or flat type are arranged in two rows on the opposite sides of the crankshaft, an especially good arrangement in streamlining. The cylinders in the single-row radial type are arranged evenly in a circle in the crankshaft, the cylinders extending radially from the center line of the crankshaft. The number of cylinders varies from three to nine, the odd number helping to produce smoother operation since one piston is always in a position for firing. The cylinders in the double-row radial type are arranged in two staggered rows in the crankshaft. This arrangement is especially desirable because the cylinders receive more air for cooling. All these types of engines use one crankshaft to drive the propeller.

Cooling systems of aircraft engines. In air-cooled engines cooling fins are used to dissipate the heat generated in high-temperature engines. To keep the engines from becoming too hot, because of the compression of gas and heat generated by the explosions, the cooling systems must cause the engines to lose about 30 per cent of the heat that they generate. In the construction of a cooling system used in air-cooled engines the following fundamental physical laws are observed: (1) the rate of cooling is directly proportional to the area exposed to the air; (2) the rate of cooling depends upon the heat conductivity of the material used; (3) the rate of cooling varies directly with the mass of the air that flows over the surface; (4) the rate of cooling varies directly with the volume of metal; and (5) the rate of cooling varies directly with the difference between the absolute temperature of the cooling surface and that of the cooling air.

In liquid-cooled engines the same laws apply except that radiator tubes and cores furnish the cooling surface. Therefore the rate of cooling depends upon the area of the tubes and cores of the radiator. It also varies as the quantity of liquid that comes in contact, indirectly, with the propeller slipstream and as the rate of flow of the liquid up to a certain speed. The cooling device of a liquid-cooled engine consists of steel barrels inserted

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in a jacket. The cooling liquid is circulated by a pump through recesses in the jacket that absorbs the heat from the cylinder barrels and transfers it to the radiator where it is given off to the air. Water and ethylene glycol are used as coolants. The latter will not evaporate so quickly as water, it has a higher boiling point and a lower freezing point than water, and it contracts when it freezes whereas water expands when it freezes. Its disadvantages as compared to water are that it has a low specific heat and is not so available as water.

The important parts of an airplane engine. The parts of an airplane engine are similar to the parts of an automobile engine except that certain parts are more complex. The piston compresses the mixture of gas and air in the cylinder, transmits the impulse of combustion to the crankshaft, and expels the burned gases from the cylinder. A connecting rod attaches the piston to the crankshaft and hence transmits power from the piston to the crankshaft. The crankshaft in turn is attached to the propeller and transmits power to the propeller. The length and complexity of the crankshaft, as shown in Figure 148, depends upon the number of pistons, one piston being attached to each arm of the crankshaft. A crankshaft must be of sturdy construction and delicately balanced. Usually it is constructed of chrome-nickel steel.

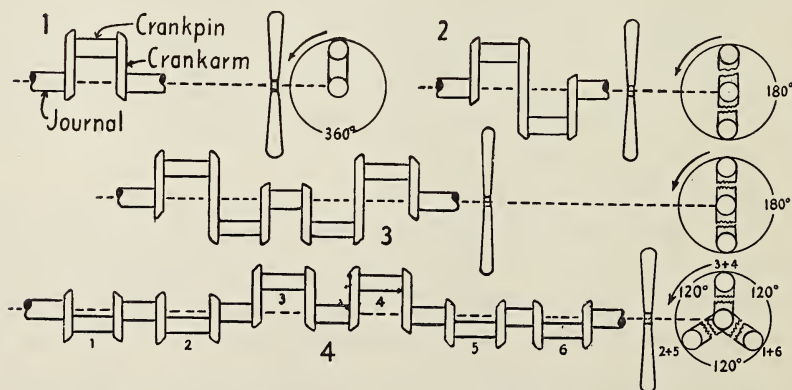


Fig. 148. Drawings of the essential working parts of various types of crankshafts.

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The bearings of the engine are especially important because the engine operates at very high speed. Three kinds of bearings are used; namely, plain bearings, roller bearings, and ball bearings. The plain bearings are used where friction is of little importance, roller bearings where friction must be somewhat reduced, and ball bearings where friction must be reduced to a minimum.

The carburetor of the airplane engine works similarly to the carburetor of an ordinary combustion engine except that it contains certain parts to counteract variations in pressure. To help offset these variations, the airplane is provided with a blower, known as a supercharger, which distributes the fuel and air mixture regardless of atmospheric pressure. Thus when an airplane travels in rarefied air, the mixture remains approximately the same as when the airplane travels near the surface.

There are several types of carburetors, of which the diaphragm variable-Venturi type shown in Figure 149 is probably the most efficient. When the gasoline reaches this carburetor, it enters the main fuel chamber, where a diaphragm eliminates splashing

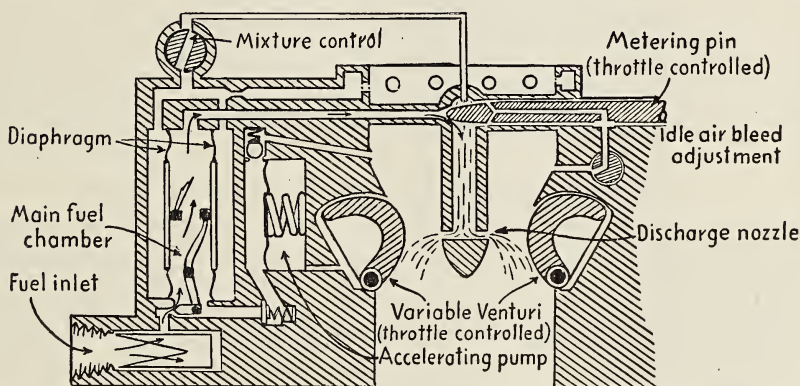


Fig. 149. Diagram showing the assembly and operation of the parts of the carburetor.

and regulates the flow. From the main fuel chamber the gasoline flows through pipes, as indicated by the arrows, to a discharge nozzle which releases it in the form of a spray into incoming air. The air enters the carburetor from below, its flow being regulated by two winglike shutters, or throttles, in the sides of the tube. The

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movement of the air, on the basis of Bernoulli's principle, reduces the pressure in the tube, making it less than the pressure in the main fuel chamber. The difference in pressure, which acts as a suction, causes the gasoline to flow from the main fuel chamber to the discharge nozzle and also from the gasoline supply tank to the carburetor. When the gasoline spray from the supply nozzle mixes with the incoming air, it forms a vaporized fuel that passes through pipes to the cylinders of the engine. This vapor moves to the cylinders because the pistons tend to create a vacuum in the cylinders and suction takes place.

Besides the main parts of the carburetor as described above, there are parts that perform special functions. One part, for example, is an accelerating pump or diaphragm that automatically forces more gasoline into the stream when the pilot suddenly opens the throttle. The additional gasoline enriches the mixture and

thus resembles a primer on an automobile carburetor. Another part is an automatic mixture device that adjusts the fuel-air mixture to different elevations. This device is essential because the density of air decreases with elevation, and a mixture that is suitable at lower levels is too rich when the airplane reaches higher levels. Besides the automatic mixture device there is a second device, shown in Figure 150, that the pilot may control

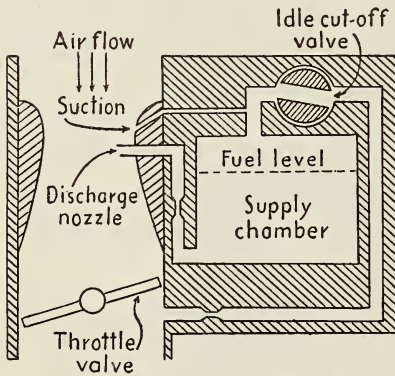


Fig. 150. Mechanism used to control the richness of the fuel mixture by suction.

by adjusting a throttle valve. This device is needed because of the danger of engine failure, especially when the engine is idling.

The aircraft propeller. The engine, of course, furnishes power to drive the propeller, which in turn provides thrust, or forward motion. Some propellers are very large, being 15 feet in length from tip to tip and weighing more than 400 pounds. Most pro-

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pellers may be adjusted mechanically by change of the blade angle, or the angle between the chord of a section of the blade and a plane perpendicular to the axis of rotation. Adjustment is important because the air decreases in density upward from the earth, offering less resistance to the propeller and thus causing the engine to increase its speed. By adjusting the blade angle the pilot can cause the propeller to meet greater resistance and indirectly reduce the speed of the engine.

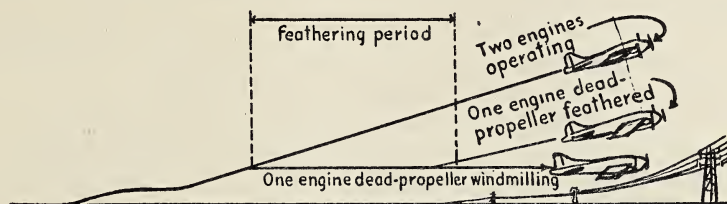
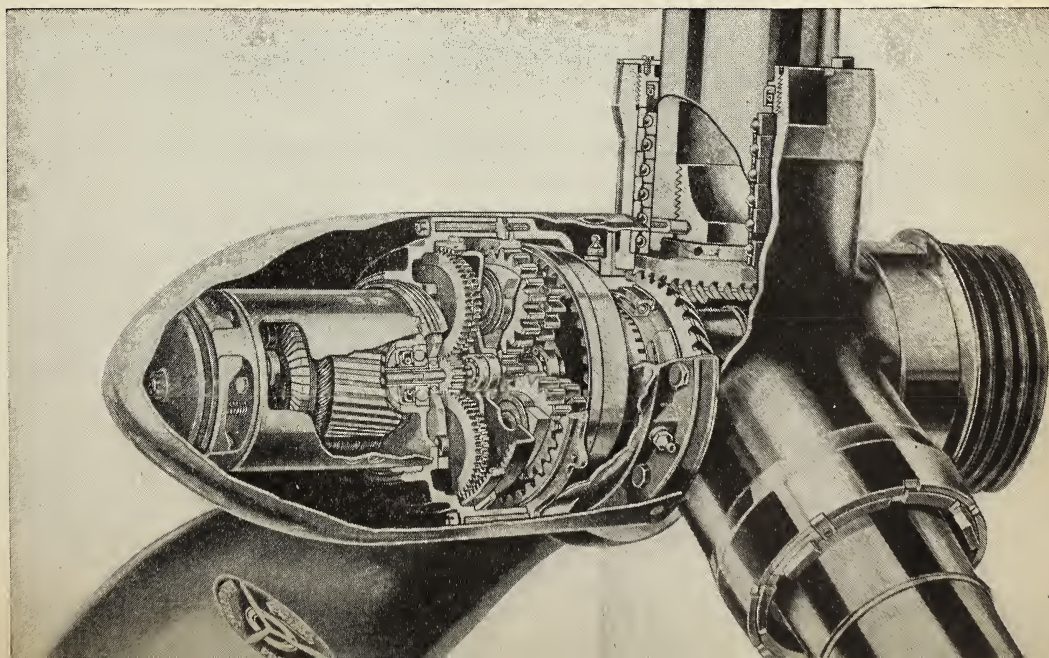


Fig. 151. Diagram showing relative effects of windmilling and feathering.

The adjustment is also important because it enables the pilot to keep an engine from rotating when it stalls or dies. Otherwise the propeller turns in the same manner as a windmill and rotates the engine, thus causing a drag that interferes greatly with the movement of the airplane as shown in Figure 151. The rotating of a dead engine by a propeller is known as windmilling, and

The picture below shows the mechanism of an electrically controlled propeller.

Ferdinand Hirsch



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adjusting the propeller blades to overcome the windmilling is known as feathering. The lower airplane in Figure 151 shows how climb is affected by windmilling, and the center airplane how climb is improved by feathering.

ANSWER THESE QUESTIONS

1. What is meant by an equivalent heat unit?
2. What interesting theories seek to explain the amount of heat energy in the universe?
3. What principle accounts for the process of refrigeration? What two important types of refrigerators are used?
4. What is meant by the quick freezing of foods?
5. What transformation of energy occurs in a steam engine?
6. Why is a steam turbine more efficient than a steam engine?
7. How does an internal-combustion engine work? What are some of the essential parts of this engine?
8. What is meant by a four-cycle internal-combustion engine?
9. What is the primary difference between a Diesel engine and an ordinary gas engine?
10. Why are spark plugs not used in a Diesel engine?
11. What are the essential parts of an airplane engine?
12. What two methods are used in cooling airplane engines?
13. How does the carburetor work in an airplane engine? Why is this carburetor much more complicated than the carburetor of an automobile engine?
14. Why are propellers of aircraft made so that their blade angle can be changed?

SOLVE THESE PROBLEMS

A

1. How many B.t.u. will 77,800 ft.-lb. of work produce if all the work is changed to heat?
2. An engine revolves 500 times per minute. The piston is 16 inches in diameter and the stroke is 2 feet. If the average pressure upon the piston is 200 lb. per square inch, how many horsepower does it develop? Assume that it has a double-action engine.
3. If the efficiency of a steam engine and boiler is 10 per cent, how much work can be delivered by 5 tons of coal if it gives 12,000 B.t.u. per pound?

B

4. What horsepower will an engine have to develop to pull a freight train of 50 cars at a constant rate of 40 mi. per hour on a level track if 500 lb. are required to overcome the resistance of each car?

5. If 500 lb. of lead fall 100 feet, how many B.t.u. are generated?

6. If a 150-HP. engine has a piston 20 in. in diameter, a 2.5-ft. stroke, and 100 r.p.m., what is the mean effective pressure?

7. If a pound of coal gives 14,500 B.t.u., how many pounds of coal will be required to develop 100 HP. for one hour provided the boiler and engine together are 20 per cent efficient?

8. A 5-ton truck traveling 40 mi. per hour is brought to a stop by means of its brakes. How many B.t.u. of heat are generated by the brakes?

9. What is the horsepower of a steam engine that has a piston 10 in. in diameter, a 16-in. stroke, 100 r.p.m., and a mean average pressure of 120 lb. per square inch?

10. What should be the diameter of a piston of a steam engine in order to develop 40 HP. if its stroke is 18 inches, its r.p.m. is 80, and its mean average pressure is 120 pounds?

11. If steam enters an engine at 250° C. and leaves it at 180° C., what is the efficiency of the engine?

12. What is the piston displacement in cubic inches of an airplane engine that has 12 cylinders, with 4-in. bore and an 8-in. stroke?

13. What part of 200 gal. of gasoline is actually used to turn the propeller if 64 per cent of it is lost by heat?

14. What is the ratio of piston displacement of two airplane engines that have 3-in. and 4-in. bores respectively?

SUMMARY

Temperature has to do with the average quantity of kinetic energy in the molecules of a body. Temperature changes cause materials to contract or expand. Because of this contraction and expansion we can measure temperature changes by the quantity certain liquids, solids, and gases expand when used in thermometers. The two common thermometer scales are the Fahrenheit and Centigrade scales. The freezing and boiling points of water under normal conditions on the Centigrade scale are 0° and 100° respectively. The corresponding points on the Fahrenheit scale are 32° and 212° respectively.

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The coefficient of linear expansion is the increase per unit length of a material as it increases one degree Centigrade. The coefficient of volume expansion is three times the coefficient of linear expansion of a material. All gases expand as their temperature increases. They all have the same coefficient of volume expansion, which is $\frac{1}{273}$ of the original volume at 0° Centigrade. When the temperature decreases in certain gases, a point may be reached where there is almost no molecular motion in the gases. The point where there is no motion of the molecules is called absolute zero and the scale based upon absolute zero is called the Absolute scale. Absolute zero is 273° below 0° on the Centigrade scale. The laws for gases formulated by Charles and verified by Gay-Lussac are: (a) *If the pressure is constant, the volume is directly proportional to the absolute temperature.* (b) *If the volume is constant, the pressure is directly proportional to the absolute temperature.*

Heat depends upon the average kinetic energy of the molecules of a body and the number and kind of molecules that are in motion. The two common units of heat are the British thermal unit (B.t.u.) and the calorie. The B.t.u. is the quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit. The calorie is the quantity of heat required to raise the temperature of one gram of water one degree Centigrade. Specific heat is the heat required to raise the temperature of a unit mass of a substance a unit degree.

Heat of fusion is the number of heat units required to change one unit mass of a substance from a solid to a liquid without changing the temperature. The heat of fusion of ice is approximately 80 calories per gram. The freezing point of water can be lowered by increasing the pressure upon it or by dissolving salts in the water.

Heat of vaporization is the number of heat units required to change a unit mass of a liquid at its boiling point into a gas without changing its temperature. The heat of vaporization of water is approximately 540 calories per gram. The boiling point of a liquid is the temperature at which the vapor pressure is

equal to the pressure upon the surface of the liquid. It can be raised or lowered by decreasing or increasing the pressure. It can also be raised by dissolving salts in the liquid. The temperature of a liquid can never be higher than its boiling point.

Evaporation is the changing of the molecules of liquids or solids at their surfaces into a vapor. It may occur at any temperature. In solids evaporation is sometimes called sublimation. Evaporation depends upon the kind of material, the area, the temperature, and the relative humidity. Relative humidity is the ratio of the quantity of vapor in the air to the quantity of vapor required to saturate the air. The higher the temperature, the more moisture the air can hold before it becomes saturated.

The transference of heat may be accomplished by convection, conduction, or radiation. The process by which heat is transferred from one place to another by means of a current is called convection. The process of transmitting heat energy through a body from molecule to molecule is called conduction. When heat is transmitted through space it travels in the form of waves. This process is called radiation. Heat radiates in straight lines with the same velocity as light.

Equivalent heat energy units of work are the number of work units required to produce one heat unit of energy. A total of 778 foot-pounds of work equals one B.t.u., whereas 427 gram-meters of work equals one calorie.

The control of heat in refrigeration is accomplished by ice and by mechanical means. Mechanical refrigeration is possible because certain gases can be compressed and become liquids at ordinary temperatures. Refrigeration by absorption is the basis of operation of the gas refrigerator.

Meteorology is the study of elements that affect the weather. Sea navigators as well as laymen must understand these elements and their effect upon weather. Aircraft pilots must understand the movements of the air and the effect of movements upon flying.

The United States Weather Bureau collects data and issues weather forecasts to aid air navigators. The characteristics of air masses, air pressure, humidity, and temperature are valuable in-

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formation for the air pilot. The characteristics of clouds help to determine the weather conditions.

Airplanes are powered with internal-combustion engines. Some of the important modern developments in airplane engines are an increase in horsepower per unit weight, the supercharger, which permits flying at greater altitudes, and the carburetor, which permits proper mixing of air and gas under all flying conditions.

A cake of ice is 0°C . Does it contain heat? Give reasons.

Why was the freezing point marked 0° on the Centigrade scale and 32° on the Fahrenheit scale?

What is normal body temperature on the Centigrade scale?

Is a steel flagpole taller in the summer than in the winter? Why?

When a lake freezes, it causes the surrounding air to become warmer. Why?

Which has more heat, a gallon of water at 0°C . or a piece of ice the same weight as the water at 0°C .? Why?

Why will a burn caused by steam at 100°C . be more severe than a burn caused by the same quantity of water at 100°C .?

Is it possible to boil and freeze water at the same time? Explain.

How can a high relative humidity in your home during cold weather reduce your fuel bill?

Why does a tile floor in your bathroom feel cool to your bare feet when a rug at the same temperature feels warm?

How can water be frozen by the application of heat?

How do air masses affect weather conditions?

How do aircraft pilots use the information given to them by the United States Weather Bureau?

Why is it important that aircraft pilots understand the elements that affect weather?

How has the power of airplane engines been increased per unit weight?

What modern development in the propeller has made flying safer and more efficient?

SOLVE THESE PROBLEMS

1. On a hot summer day the Fahrenheit thermometer reads 100° . What would the reading be on a Centigrade thermometer?

2. If the coefficient of linear expansion of steel is 0.000011, how much longer is a steel rail on a hot summer day when the Centigrade

INVESTIGATIONS

thermometer reads 35° than on a cold winter day when the Centigrade thermometer reads -20° and the rail is 60 ft. long?

3. An automobile tire is pumped up to 30 lb. per square inch when the temperature is -10° Centigrade. What will be the pressure when the temperature is 30° Centigrade? (The volume of tire is to remain constant.)

4. A gas tank contains 200,000 cu. ft. of gas under a pressure of 40 lb. per square inch at 30° Centigrade. What is its pressure at -10° Centigrade?

5. The temperature of a gas is 98° Fahrenheit. What is the temperature on the Absolute scale?

6. A teakettle holds 10 lb. of water at 40° Fahrenheit. How many B.t.u. are required to raise the temperature to 98° Fahrenheit?

7. A kilogram of iron is 70° Fahrenheit. How many calories of heat are required to raise it to a temperature of 200° Fahrenheit?

8. How many calories of heat will the melting of 20 kg. of ice remove from an icebox?

9. How many calories of heat are required to melt 500 g. of ice at -10° C. and raise the temperature of the water formed by it to 100° Centigrade?

10. Five hundred kg. of steam is passed into a steam radiator. As it passes through, it condenses and the water leaves the radiator at 90° Centigrade. How many calories of heat did it give up to the radiator?

11. How many calories of heat are required to change 100 g. of ice at -20° C. to steam at 100° Centigrade?

12. The B.t.u. of a pound of coal is 12,000. If 10 per cent of the heat energy from the coal is changed to work, how many foot-pounds of work will it do?

13. Under similar flying conditions, if an airplane doubles its speed, how much has its output horsepower increased?

14. If an aircraft engine can develop 650 horsepower, how much does it weigh if it develops 1 horsepower for each $1\frac{1}{4}$ lb. of weight?

INVESTIGATIONS

1. Test a thermometer to see if its freezing and boiling points are accurate.

2. Examine a thermostat to find out how it is constructed and explain how it works.

3. Notice the joints of the rails of a railroad and compare the distance between the ends of the rails when the weather is warm and when it is cold.

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4. Check the pressure of automobile tires in the morning at the beginning of a trip on a warm day and check them again later in the day. Compare and explain the results.

5. Find out from a coal dealer how many B.t.u. are in a pound of different kinds of coal. Also find their fusion points and ash content.

6. Examine both steam and hot-water heating systems and compare their construction and working principles.

7. Find out how a hot-air heating system works.

8. Inspect an air-conditioning system and see how it works.

9. Visit an artificial-ice plant to see how ice is made.

10. Inspect the quick-freeze system in a grocery store and explain how it works.

11. Secure diagrams of mechanical and gas refrigerators from refrigerator dealers and follow the circuit of the refrigerant.

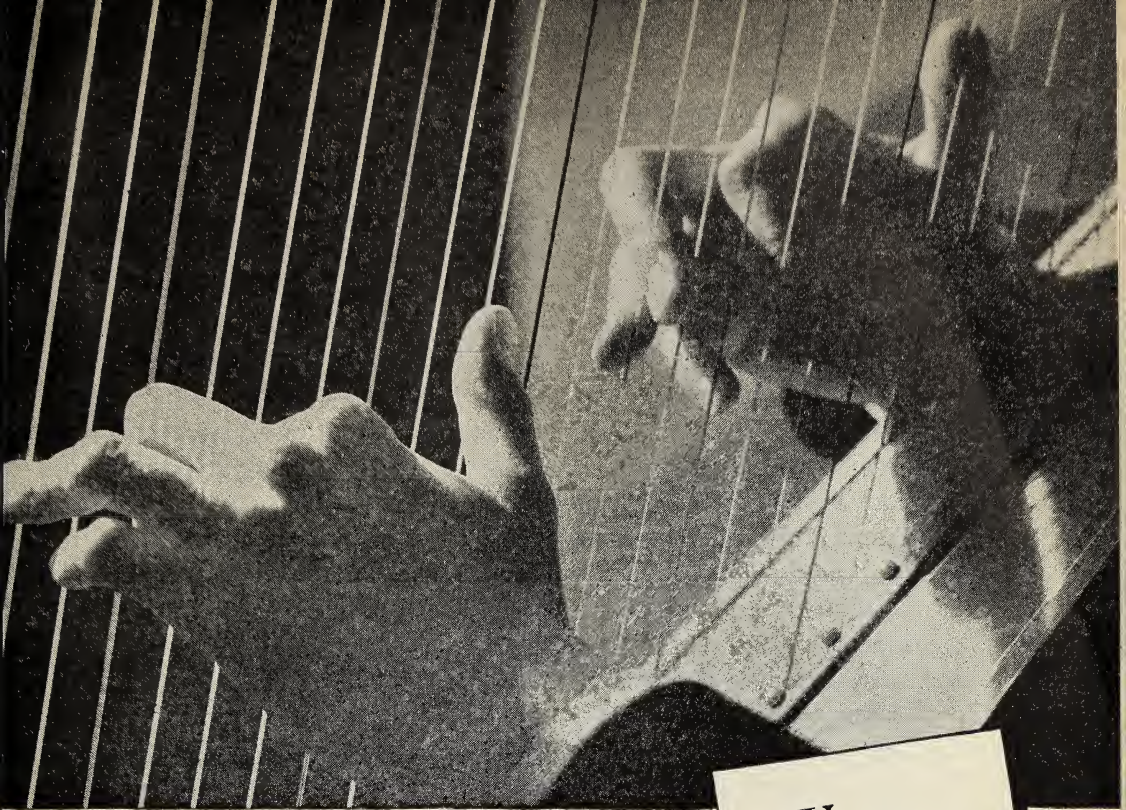
12. Visit a community cold-storage place and find out how it works.

13. Visit a United States Weather Bureau Station and see how meteorological elements are measured.

14. Talk with an aircraft pilot and find out how he uses weather information.

15. Investigate the types of engines used in different kinds of aircraft.

16. Observe and compare the propellers of different airplanes and notice particularly their shapes.



The beautiful music produced by these skillful fingers depends upon the vibrations of harpstrings that have been arranged and tuned according to definite laws of sound.

Exploring the World of Sound

MUSIC AND NOISE

You have heard the members of your school orchestra or band tuning their instruments simultaneously, preparing to play a musical selection as a unit. The sounds that they produced were far from harmonious and even “grated” on your ears, for each person was concerned only with tuning his own instrument. When the director took his position before the group, gave the

UNIT SIX

EXPLORING THE WORLD OF SOUND

signal to begin playing, and directed the playing, the sounds were harmoniously blended and timed. The members of the group played their instruments together according to the plan prepared by the composer and indicated on printed sheets. The result was music. The result of the planless tuning of instruments was noise. The individual sounds that were produced in both cases were the same kinds of sounds, but the effect upon the listeners was vastly different. The appreciation of sound effects, of course, varies a great deal in different individuals. Even the same individual may like a sound or combination of sounds on one day and on the next day dislike it exceedingly. But in general it is conceded that sounds or planned combinations of sounds that are pleasing to the ear are musical, and any sound or combination of sounds that displeases is noise.

In a certain high school a student of physics carefully selected eight pieces of hardwood and laboriously cut them into certain lengths, thicknesses, and widths, until each stick, when dropped upon a hard surface, produced a different note of the musical scale. In an auditorium program he demonstrated before the student body the difference between music and noise by first dropping the eight pieces of wood together upon a hard surface. The result was what you would hear if you dropped an armload of firewood on the floor all in a heap. He next proceeded to drop the sticks one at a time in the order of their pitch, and the result was a musical scale. Again he dropped the sticks one by one, but this time in the order and with the rhythm necessary to produce the melody of the school song. Needless to say, the audience was immensely pleased. Incidentally, the performance also illustrated the principle upon which the popular musical instrument called the xylophone is constructed.

In the preceding paragraphs you have read about examples illustrating the differences between sounds, but you probably do not yet fully understand the differences. This is not surprising. You will have to understand many other related problems, such as: What determines the pitch of a note? Why do different musical instruments sound different even though the same musical

WHAT SOUND IS

melodies are produced by them? How fast does sound travel? How are the principles of sound used to make acoustics better in public buildings and auditoriums? How can people with defective hearing be made to hear? How can noises be reduced in city streets and factories? These and other problems of the physics of sound are discussed in this unit.

AREAS OF STUDY

1. *What is sound?*
2. *How is sound transmitted from one place or object to another?*
3. *Why are some sounds louder than others?*
4. *What happens when sounds are reflected?*
5. *How are musical sounds produced?*

AREA ONE

What Is Sound?

What a different world this would be if we could not hear sounds. Through our hearing we are warned of danger, hear the conversation of our friends, and listen to music. Through the radio our interests are broadened as we hear about all the important events taking place in the world. The voices of the great leaders in government and business tell us what is happening and explain their policies. We hear equally well the opening speeches at the automobile show and the inauguration of a president. How it is possible to hear music and the voices of people at great distances involves the study, not only of sound waves, which we shall consider in this unit, but also of electricity and electromagnetic waves, which we shall consider in later units. But we must first try to discover what sound really is and what causes the phenomenon.

EXPLORING THE WORLD OF SOUND

Must a sound be heard? Most of us probably have heard the question, "If a tree were to fall in a wilderness far from any living creature, would there be any sound?" This question may be answered by either "Yes" or "No." The answer depends upon the meaning we give to sound. To most of us the word *sound* means a sensation, but to a physicist it means a vibratory motion that will cause the sensation of sound in ears that are present to hear it. One definition of sound, then, is that it is energy transmitted through a medium in the form of vibratory motion that produces a sensation in the auditory nerves.

What makes sound? Every sound, if traced back to its source, will be found to be caused by the vibration of some body. By

This young man is producing vibrations in the drum which cause a sensation of sound that is evidently pleasing to his ears and possibly to those of his audience.

Ferdinand Hirsch



vibration we mean the to-and-fro motion of a pendulum when it is made to swing as shown in Figure 152 or the motion of a steel strip when clamped at one end and struck a sharp blow at the other as shown in Figure 153. Another example is a spring fastened at one end with a weight at the other. When the weight is pulled down and released, it moves up and down. Figure 154 represents a brass rod 100 centimeters long, clamped at the middle point and touching a suspended ball.

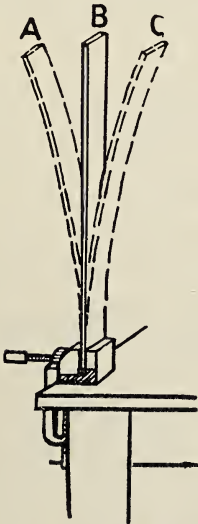


Fig. 153. The steel vibrates when struck.

When the rod is stroked with a resined cloth, a shrill sound is produced and the ball rebounds from the end, showing that the rod is vibrating strongly in the direction of its length. In Figure 152 the movement from A to C constitutes a single vibration, and the movement from A to C and return a complete vibration. The maximum displacement of a vibrating body from the middle point—B to A—is called the amplitude of the vibration. The

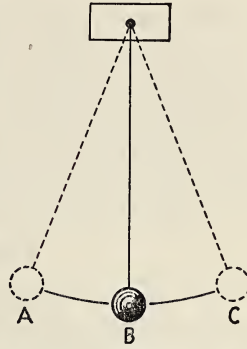


Fig. 152. Vibrations of a swinging pendulum.

period is the time required for one complete vibration. The frequency is the number of vibrations per second. Every elastic body has its own natural period of vibration, depending upon the dimensions and the degree of elasticity of the body. If the tips of a vibrating tuning fork

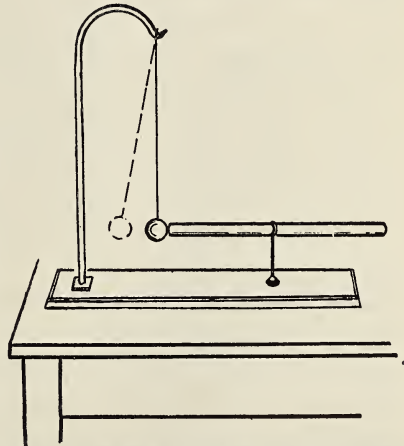


Fig. 154. Intense vibration in the rod causes the ball to rebound sharply from the end.

EXPLORING THE WORLD OF SOUND

are thrust into water, a fine spray will form. A small glass ball or any light body will rebound from the prongs of a vibrating fork. After a drum is struck, the vibrations in the drumhead can be felt. When a string on a guitar or other stringed instrument is plucked, the string will be seen to form a narrow band of vibration and a musical note will be heard. Many other experiments might be used to show that sound arises from the vibration of matter. If, then, the sensation of sound is caused by the vibration of matter, why is no sound produced by the vibration of a pendulum?

ANSWER THESE QUESTIONS

1. What vibrates when one talks?
2. What is the vibrating material when a whistle is blown?
3. Do all vibrations produce sound?

AREA TWO

How Is Sound Transmitted from One Place or Object to Another?

We know now that sound is caused by the vibration of matter. We can understand, too, that the effect of this vibration must reach our ears through whatever medium exists between the vibrating body and our ears in order for us to hear sound. We will now see how a vibrating body sets up wave motions in the medium surrounding it, and we will examine the different media for their ability to transmit vibrations. We will also examine the characteristics of the wave motion itself.

Sound waves and elasticity. If you put your ear to the rail, you can hear the approach of a train while it is still far away. If a pipe in the basement is struck with a hammer, the sound can be heard all through the building. These experiments show that sounds travel readily through solids. However, if two stones are struck together under water, the sound heard by the ear held

HOW SOUND IS TRANSMITTED

under the water is louder than it is when both stones and ear are in the air. Most sounds reach the ear through the air. In other words, sound is transmitted from the source through matter as a medium. The capacity of matter to transmit sound depends upon its elasticity. For this reason solids are generally better media than liquids or gases. But some solids are poor media for transmitting sounds. Rugs covering the floor help to prevent noise. The floors of libraries are often covered with cork matting. A pad of felt on the dining-room table prevents the clatter of dishes. Such materials as fabrics, cork, and felt do not transmit sounds very well because they do not possess much elasticity.

Sound through water. Liquids in general are better conductors of sounds than gases, though not so good as elastic solids. During the First World War, vessels were fitted with listening devices or "ears" to detect the presence of submarines. Since that time other methods have been developed for locating the positions of ships by recording sounds transmitted through the water.

No sound through a vacuum. That matter is necessary for the transmission of sound may be shown by the fact that it will not pass through a vacuum. One way of showing this is by placing an electric bell within a bell jar as shown in Figure 155 and connecting the binding posts on the outside of the bell jar to a dry cell. When the electric circuit is closed, the bell can be heard. As the air is withdrawn, the sound of the bell becomes fainter. The success of this experiment depends upon the inelasticity of the materials used to support the bell and upon the degree of rarefaction produced in the bell jar.

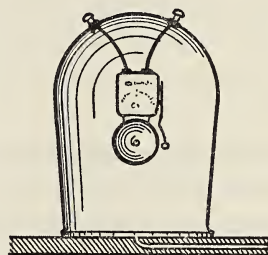


Fig. 155. The ringing of a bell in a vacuum cannot be heard.

How fast does sound travel? Thunder is heard some time after the flash of the lightning is seen. When watching a man working with a hammer some distance away, we see that the blow is

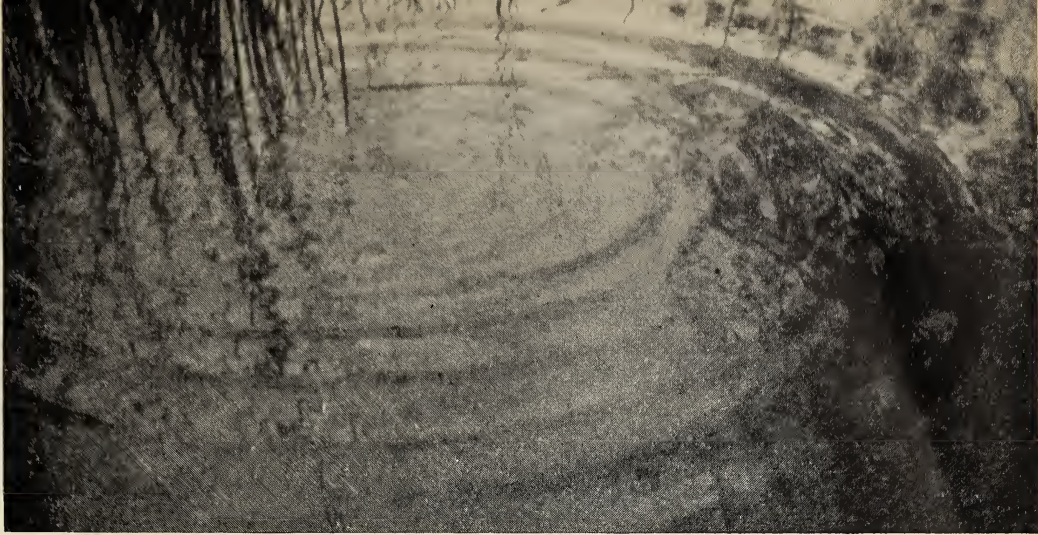
EXPLORING THE WORLD OF SOUND

struck an appreciable time before we hear the sound. These facts are evidences that sound travels more slowly than light. The velocity of sound in air was first determined by French scientists in 1738. Cannon were placed on two hills several miles apart and fired alternately. The distance between the hills was measured and the time between the flash and the report noted. From this data, the distance traveled per second was calculated.

The average of a large number of trials by different methods shows the velocity of sound to be about 331 meters, or 1089 feet, per second in air at a temperature of 0° C. and a barometric pressure of 76 centimeters.

Velocity of sound in relation to the elasticity and density of the medium. The velocity of sound in any medium depends upon the elasticity of the medium and upon its density. In general, the greater the elasticity of the medium the greater is the velocity of sound, and the greater the density the less the velocity. Solids have a greater density generally than liquids and gases, but the velocity of sound in solids is greater than in liquids or gases because the elasticity of solids is much greater in comparison with the density. The velocity of sound in steel is 5000 meters, or 16,410 feet, per second. The velocity of sound in lead is 1227 meters, or 4026 feet, per second. Lead has a greater density than steel, but its elasticity is much less than the elasticity of steel. The velocity of sound in water at 15° C. is 1437 meters, or 4714 feet, per second.

Velocity in relation to temperature. An increase in the temperature will cause an increase in the velocity of sound in air. This is to be expected. As the temperature rises, if the air is free to expand, its density decreases, thus making the velocity of sound increase. If the air is inclosed so that it cannot expand, its pressure increases, thus causing an increase in elasticity and hence an increase in velocity of sound. A change of 1° C. causes an increase of two feet per second or 60 centimeters per second in the velocity of sound in air. Does sound travel faster in the rare air



A jumping frog or falling twig sets up a succession of waves that travel outward from the region of disturbance in ever widening concentric circles.

at the top of a high mountain than at the level of the sea where the density of the air is greater? No; provided the temperature is the same, sound travels at the same rate in both places because, although the air is denser at sea level, its pressure is also greater, and hence its elasticity is greater.

Since different gases at the same pressure and temperature have the same elasticity, the velocity of sound in them varies inversely as the square root of the density. Thus, the density of hydrogen being about one-fourteenth the density of air, the velocity of sound in hydrogen is almost four times the velocity in air.

The nature of wave motion. The most familiar waves are water waves. If such waves are set up by a pebble dropped into a pond, we see a series of ridges and hollows, or crests and troughs, that spread out in concentric circles from the center of disturbance. That the water itself does not travel with the wave may be shown by the motion of a chip or leaf floating on the surface. As the wave moves forward, the motion of the leaf is up and down, but it does not move forward with the wave. A wave motion is thus the passage of vibratory energy through a medium from particle to particle, each particle remaining in the same relative position when the vibratory energy has passed.

EXPLORING THE WORLD OF SOUND

There are two kinds of vibratory motion, or waves, the transverse and the longitudinal. A transverse wave is one in which the vibrating particle moves at right angles to the direction of the motion of the wave. The water wave is a good example of the transverse wave. Such a wave can be produced in a heavy cord



Fig. 156. Illustration of transverse wave motion.

or a length of rubber tubing attached to a wall as shown in Figure 156. A wave can be started along it if the end A is moved up and down at

right angles to its length. If the motion of the hand is continuous, a continuous series of waves travels along the tubing. This continuous series of waves is called a wave train. In Figure 157 this wave train is represented by a simple curve, sometimes called a sine curve. We can get a clearer idea of the motions which take place in producing the wave by a study of the drawing. The direction in which the wave is traveling is shown by the long

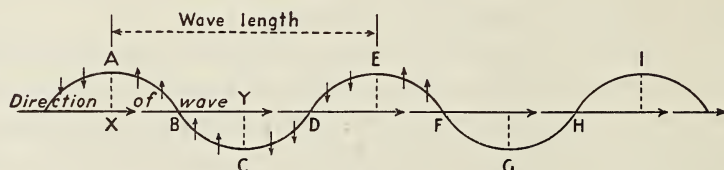


Fig. 157. Diagram illustrating the movement of particles in a transverse wave.

arrows. The motion of the individual particles at a given time is shown by the small arrows. At A, E, and I the particles are at the highest points, and the next instant they will start down. The particles at C and G are at the lowest points and will move up. At B and F the particles are moving up, at D and H the particles are moving down.

The particles A, E, and I are in the same relative position and move in the same direction. Likewise the particles at B and F are in the same relative position and move in the same direction. At the points A, E, and I the waves are said to be in the same phase. They are also in the same phase at the points B and F.

HOW SOUND IS TRANSMITTED

In other words, two waves are said to be in the same phase at certain points when the particles or the part of the wave at those points are in exactly the same position and are moving in the same direction.

In Figure 157 the distance from X to A , or from Y to C , represents the greatest displacement, or the amplitude, of the wave. The part at A is known as the crest and the part at C as the trough. The distance from A to E is the wave length. However, the distance from any one point, as B , to any other point in the same phase, as F , also represents the wave length. The distance from C to G or from D to H may also be taken as the wave length.

Longitudinal wave in a spring. Let a spiral spring several feet in length be attached at the end B as shown in Figure 158. If several turns of this spring near the end A are pinched together and released, a wave of compression is seen to travel up the spring to B and return. If several turns near A are pulled apart and then released, this stretch is seen to travel up to B and return.

When the compressed turns of the spring are released, they spring apart and transfer their energy to the turns just above, causing them to move slightly upward and form a compression, which will cause a squeezing together of the turns still farther up. In this way the wave of compression travels along this spring. In like manner when the turns that have been pulled apart are released, they spring together. This downward motion is communicated to the turns immediately above and by these to others farther up, and so this downward movement of the turns causes a wave of stretch

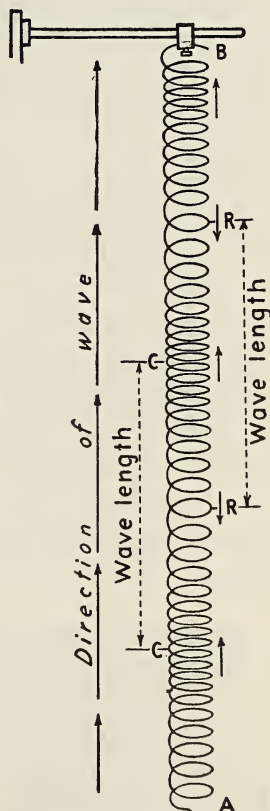


Fig. 158. Characteristics of a longitudinal wave.

EXPLORING THE WORLD OF SOUND

to move up the spring. If these experiments are repeated, close observation will show that each pulse of compression is immediately followed by a pulse of stretching. This is to be expected because a compression of the turns must be accompanied by a pulling apart of the turns. In the preceding drawing is shown a train of waves traveling up the spiral spring. The compression of the turns is called a condensation and is marked *C* in the figure. The stretched part is called a rarefaction and is marked *R*. Such a wave in a spiral spring is called a longitudinal wave because all the motions of the individual turns producing the condensations and rarefactions are along the length of the spring.

This motion of each individual turn of the spring is a sharp jerk upward and downward. For the condensation the jerk is upward in the direction of the motion of the wave. For the rarefaction the jerk is downward, or in a direction opposite to the direction of the wave, as shown in the preceding drawing. This experiment shows that energy is transmitted from turn to turn and is propagated throughout the length of the spring with but little motion of each turn.

The distance from a condensation to the next condensation or from a rarefaction to the next rarefaction is a wave length. The distance of greatest displacement of each turn from its position at rest, on either side of such position, is the amplitude of the wave. The number of complete waves (condensation and rarefaction) passing along the spring per second is the frequency.

A mechanical illustration of the fact that energy will travel through individual particles is shown in Figure 159. The apparatus consists of a number of steel balls hung so that they just

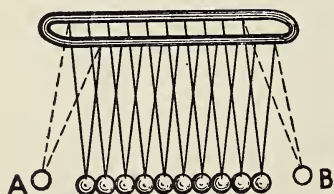


Fig. 159. The energy of vibrations travels from particle to particle.

touch one another. If we pull aside ball *A* and let it fall back against the line of balls, the ball it strikes does not seem to move, nor does the next one. None of the balls is seen to move except ball *B* on the end, which flies out and rises approximately to the same height as that from which

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the first was dropped. Since the ball *B* was moved from the end, work was done upon it, and the energy that did this work was transmitted through these balls as an elastic medium, practically undiminished and with no perceptible motion of the balls intervening between *A* and *B*.

What kind of waves are sound waves? Are sound waves transverse or longitudinal? Figure 160, (1), represents a tube filled with undisturbed air. For clearness, the molecules of the air are shown in equally distant parallel lines. In Figure 160, (2), the steel strip, clamped at the end of the tube, has been pulled back to *A* and released. It moves from *A* to *C*, compressing the air in front of it. Since the effect of the push of the strip is communicated from molecule to molecule of the air just as the energy of ball *A* was communicated from ball to ball in Figure 159, the effect continues to move from left to right. When the strip has reached *C*, the crowding effect on the air has traveled to *y* and the air from *x* to *y* has been condensed. When the strip moves from *C* to *A*, it leaves a partial vacuum on the right in the tube and the air molecules rush into it, creating a rarefaction. This rarefaction must continue moving to the right though the molecules producing it are actually moving to the left. When the strip has reached *A*, a rarefaction has been produced from *x* to *y* while the impulse given the molecules

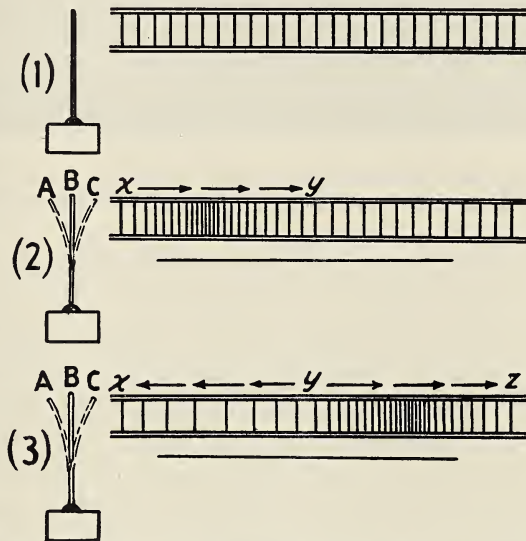


Fig. 160. Diagrams showing condensations and rarefactions produced as sound waves pass through a tube.



Century Photos, Inc.

Speaking tubes conduct voice vibrations from apartment to corridor or corridor to apartment just as the tube in our experiment conducted the vibrations of the strip of steel.

by the strip moving from *A* to *C* has been passed on from molecule to molecule. In Figure 160, (3), we see a condensation in the molecules from *y* to *z*. The wave passes on through the air in the tube. Each vibration of the strip repeats this effect, and we have a continuous train of condensations and rarefactions.

If the ear is at the other end of the tube, these condensations and rarefactions will cause the sound to be heard. We can thus see how the energy of a vibrating body is communicated to the molecules of the air and passed on by them. The movement of the air molecules is very slight, just a small to-and-fro movement much smaller than that of each individual turn in the spiral spring. This back-and-forth movement, however, is along the line of direction of the sound wave. Sound waves, then, are longitudinal.

Graphic representation of sound waves. For the purpose of the study of different properties of sound it is often convenient to represent sound waves graphically. Since sound waves are longitudinal, they can be represented by a series of parallel lines

HOW SOUND IS TRANSMITTED

as shown in Figure 161, (1). Transverse waves are represented by drawing the actual shape of the curve, shown by Figure 161, (2). By comparing Figure 161, (1), and Figure 161, (2), we see that a condensation of a longitudinal wave corresponds to the crest of a transverse wave and a rarefaction corresponds to the trough. A sound wave may, then, be shown graphically by a straight horizontal line. Then at points such as *a, b, c, d, e*, etc., Figure 161, (3), the amount of the displacement of the molecules in the longitudinal wave can be represented by the erection of perpendiculars of the proper relative length. For example, the displacement at *a, c, e, g*, and *i* is zero; that is, the density of the air is normal. At *b* the length of the perpendicular represents the density of the air above its normal density. At *d* the length of the perpendicular represents the density of the air below its normal density. By drawing a smooth curve through these points we have a graphic representation of sound.

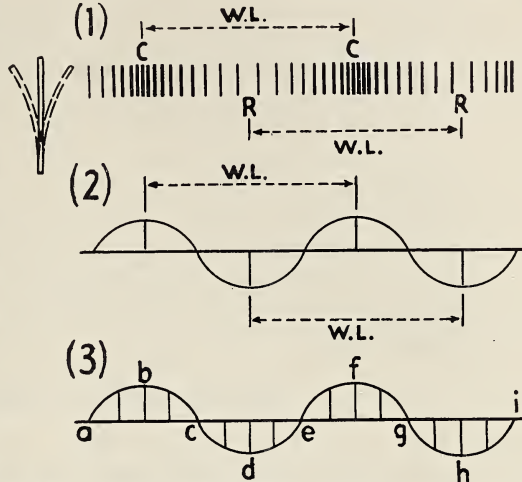


Fig. 161. Diagrams showing the important parts and characteristics of transverse and longitudinal sound waves.

Relation of velocity, wave length, and frequency. Since a wave length is the distance (L) of the disturbance caused by one vibration, and frequency is the number (N) of wave lengths produced in one second, the velocity of the wave (V), or the distance it travels per second, is equal to the product of the wave length times the frequency. Expressed in the form of an equation, this relationship is as follows: $V = L \times N$ or $L = \frac{V}{N}$.

EXPLORING THE WORLD OF SOUND

ANSWER THESE QUESTIONS

1. Why did an Indian sometimes put his ear to the ground when he wanted to hear a distant sound more distinctly?
2. Why does sound travel faster through steel than through air?
3. What is a transverse wave? Represent it by a drawing.
4. What is a longitudinal wave? Represent it by a drawing.
5. What kind of wave is a sound wave?
6. Why will sound not travel through a vacuum?
7. What is meant by the wave length of a sound wave?
8. What is the amplitude of a sound wave?
9. What is meant by the frequency of a sound wave?
10. What is a rarefaction? a condensation?
11. Why will sound travel faster on a warm day than on a cold day?
12. How are rooms made soundproof?
13. How do you explain the principle of a bone-conduction hearing apparatus?

SOLVE THESE PROBLEMS

A

1. At 0°C. , how far will sound travel in 3 seconds?
2. Three seconds elapse between the flash of lightning and the thunderclap. How far away is the lightning if the temperature is 30°C. ?
3. A tuning fork has a frequency of 256 vibrations per second. The temperature is 25°C. What is the wave length of the sound?
4. How far away is a cliff from a boy who hears the echo in two seconds after uttering a sound, the temperature being 20°C. ?
5. A steamboat whistle is heard four seconds after the steam is seen. How far away is the boat if the temperature is 15°C. ?

B

6. A man sets his watch by a whistle three miles away. On a summer day when the temperature is 30°C. , how much too slow is the watch?
7. A bullet fired from a gun with a speed of 1200 ft. per second is heard to strike the target in 6 seconds after the gun is fired. What is the distance to the target if the temperature is 21.5°C. ?
8. On a day when the temperature was 20.5°C. , a boy dropped a stone from a cliff to water below. He timed the period that elapsed before he heard the splash. The top of the cliff was said to be 1600 feet above the water. How much time should elapse if this height is correct?

WHY SOME SOUNDS ARE LOUDER THAN OTHERS

AREA THREE

Why Are Some Sounds Louder than Others?

The sound wave has been examined to discover how it originates and what some of its general characteristics are. But we have not learned why some sounds are loud and some faint. Why does a megaphone help us to hear the voice of the cheer leader? Why does a clock-tick sound louder when we set the clock on a table?

Intensity and loudness. Intensity of sound is measured by the quantity of energy in a sound wave passing at right angles through a surface one square centimeter in area in one second. Intensity depends upon (a) distance from origin, (b) amplitude of vibration, (c) density of the medium, and (d) area of the vibrating body.

By loudness is meant the apparent strength of the sensation received by the eardrum. A unit called the bel is used for the measurement of the relative loudness of sounds. For ordinary sounds ranging from those in the quiet countryside to the noise of a pneumatic drill in city streets, a tenth of a bel, or decibel, is the unit of measurement most commonly used.

Relation of intensity or loudness to distance. We all know that as we walk away from a sounding body the loudness decreases as the distance increases. When a sounding body is set in vibration,

The megaphone conveys with undiminished vigor the voice of encouragement to the team from this cheerful row of rooters on the side lines.

Paul Photos



EXPLORING THE WORLD OF SOUND

the sound moves out from it in all directions in concentric spheres as shown in Figure 162. As the waves move outward, the area of the spherical surface of the wave front increases; and, as there is a limited amount of energy communicated to the air by the

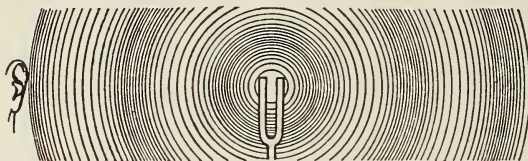


Fig. 162. The vibrations of the tuning fork set up spherical sound waves that move outward in all directions.

vibrating fork, the amount of energy received by one unit of area must decrease in just the proportion in which the area of the wave increases. Since the area of a sphere is

$4\pi r^2$, where r is the radius of the sphere, the area of the spherical wave varies as the square of its radius or as the square of the distance from its source. The intensity of the sound energy for a unit area will then vary inversely as the square of the distance from the source. If the intensity of a sound at a distance of one foot is considered as one unit, at a distance of two feet the intensity will be one-fourth of a unit and at a distance of three feet it will be one-ninth of a unit.

The effectiveness of speaking tubes used in buildings is due to the fact that they prevent the spreading out of the sound waves and the consequent loss of intensity per unit of area. Megaphones also serve to prevent the sudden spreading out of sound waves and thus cause the energy of the wave to be sent largely in one direction.

Relation of intensity to amplitude of vibration. If a tuning fork is tapped lightly, a faint sound is heard. If it is struck sharply so that the prongs vibrate through a larger area, a much louder sound is produced. It can be shown that the intensity of the sound varies as the square of the amplitude of the vibrations.

Relation of intensity to the density of the medium. The experiment of the electric bell in the vacuum showed that as the air was gradually removed from the bell jar the loudness of the sound

WHAT HAPPENS WHEN SOUNDS ARE REFLECTED

became less and less. This indicates that the intensity of a sound transmitted by a medium becomes less as the density of the medium becomes less. Some of the energy will be absorbed in passing through any medium. The amount of energy absorbed in a given distance depends upon the characteristics of the medium, its elasticity, its density, its temperature, or the amount of pressure exerted upon it.

The intensity of a sound and the area of the sounding body. If a tuning fork is tapped and held in the hand, the sound is very faint. Now if the base of the fork while still in vibration is placed in contact with the top of the lecture table, the sound will become very much louder. This is true because the table is now set in vibration by the tuning fork. From this fact we may see that loudness depends upon the area of the vibrating body.

ANSWER THESE QUESTIONS

1. What is the difference between intensity and loudness of sound?
2. Upon what does the intensity of sound depend?
3. Why does a cheer leader use a megaphone?
4. What is the principle of a speaking tube?

SOLVE THESE PROBLEMS

1. If intensity of a sound is 10 units at a distance of 4 ft., what is its intensity at a distance of 8 feet?
2. The amplitude of a vibrating body is 0.1 cm. If it is caused to have an amplitude of 0.2 cm., how many times has the intensity of the sound been increased?

AREA FOUR

What Happens When Sounds Are Reflected?

In preceding areas we have found that sound is caused by vibratory movements in the medium surrounding a vibrating body. Let us now see what happens when these vibratory movements from the vibrating body come to a material of different density.

EXPLORING THE WORLD OF SOUND

Reflection of sound waves. All of us have heard echoes, and we know that we can produce an echo by shouting while standing some distance away from a cliff or a large building. It is evident, then, that the waves we send out travel through the air to the cliff or walls of the building and from there are reflected just as a ball would be reflected. The sound comes back as a separate sound, or echo, as if someone as far beyond the reflecting surface as we are in front of it were repeating our words in mimicry. If we move too close to the reflecting surface, we no longer get this echo.

Since the sensation of a sound lasts, on the average, for one-tenth of a second after the cause of the sound has ceased to exist, the human ear does not ordinarily recognize two successive sounds as being separate and distinct unless an interval of one-tenth of a second elapses between them. To reflect a distinct and separate sound, the reflecting surface must be far enough away so that more than one-tenth of a second elapses between the origin of the sound and its return. Since at ordinary temperature (20° C.) sound travels at about 1130 feet per second, or 113 feet in one-tenth of a second, and as it must travel to the reflecting surface and back, the reflector must be at a greater distance than 57 feet. If the reflecting surface is less than 57 feet, the reflected sound blends with and strengthens the original sound.

Acoustics of rooms. In large auditoriums and assembly rooms the reflection of sound waves is sometimes very troublesome. Echoes caused by the reflection of sound from smooth, curved walls or ceilings are particularly undesirable because they may give a very great intensity of sound in certain parts of the room. They can be avoided by the use of flat surfaces made irregular by the placement of beams, windows, or hangings.

Reflection from air layers. Sound waves are reflected by a layer of air having a different density from that in which the sound wave is traveling. In the daytime, even when the air is still and clear, sound waves may meet layers of air having different density owing to the different temperature, and may thus be reflected.

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Sound does not carry far under such circumstances because of the loss of energy due to reflection. At night when the air is more uniform in temperature or on cold days in winter, and especially in the cold polar regions, sound will travel long distances.

Sound waves reflected from a smooth concave surface may be brought to a focus by a similar concave surface as shown in Figure 163. The ticking of a watch placed at *A* may be heard very distinctly at *B*, although it cannot be heard at *C*, a point midway between the two. Some buildings having dome-shaped ceilings show this effect in a remarkable degree. In the Hall of Statuary in the Capitol Building whispers that are uttered near one side of the room can be heard distinctly near the opposite side although they are inaudible in the center of the room.

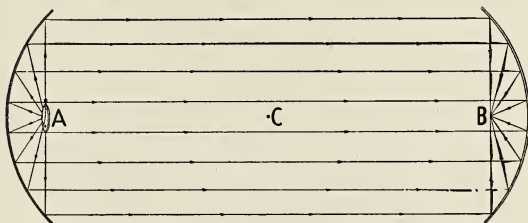


Fig. 163. Diagram showing how the ticking of a watch is reflected and focused by two concave surfaces.

In the Mormon Tabernacle in Salt Lake City a pin dropped near the choir loft can be heard clearly at any point in the auditorium, even though the most distant point is over 200 feet away. The name whispering gallery is sometimes applied to such places. In some auditoriums concave reflectors are placed behind the speaker's stand to reflect the words of the speaker forward to the audience, much as curved mirrors are put in headlights of automobiles to direct the light forward on the road. Band shells are so called because they are in the form of a shell, the concave surface of which behind the band projects the music forward.

How echoes are made useful. In foggy weather the captain of an ocean vessel is sometimes able to determine how close he is to an iceberg or a rocky coast by the time that elapses between the blast of the whistle and the return of the echo. The disadvantage of this method is that weather conditions sometimes make it hard to hear an echo and to determine the direction from which it is

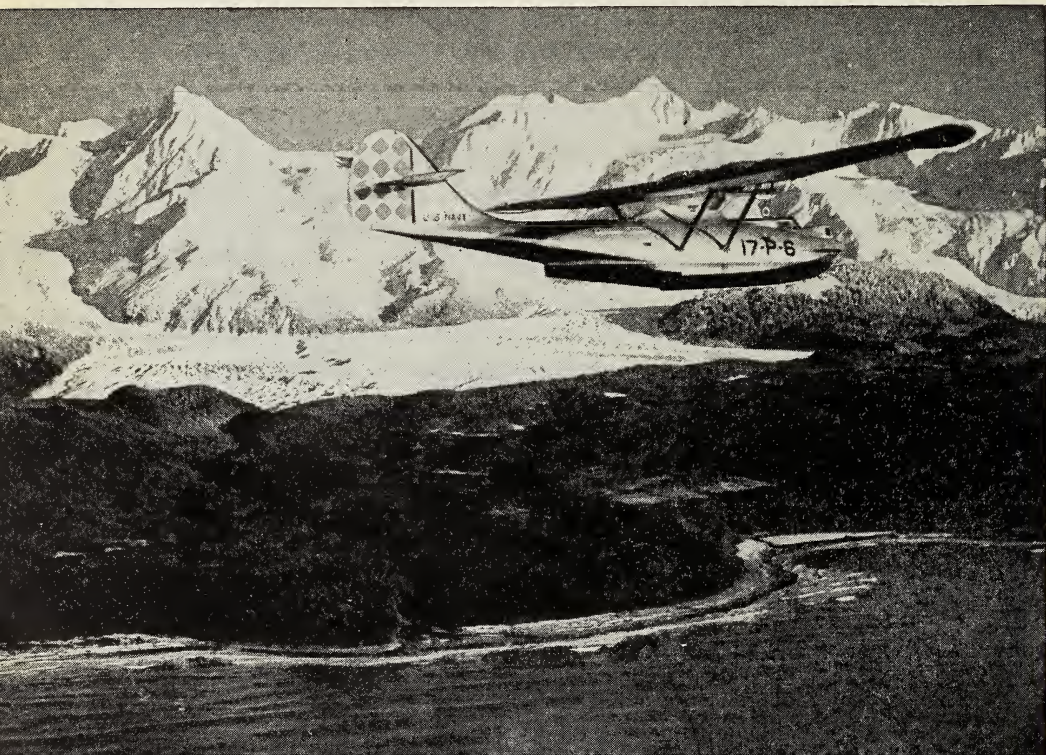
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coming. More reliance is placed upon an echo that is transmitted through the water, because water transmits sound better than air and weather conditions do not affect the transmission of sound in water. A method of locating distant objects by using the sound transmitted by water is as follows: Two microphones are placed beneath the surface of the water on opposite sides of the hull of the ship. A sound signal transmitted through one of these microphones is reflected back to the other from any object reached by the vibrations of the sound signal. Knowing the speed of sound and the length of time that has elapsed between the sending of the signal and the reception of the echo, the pilot can readily calculate the distance of the ship from the object.

The depth of the water under the ship can also be determined by sound echo. In this case a receiving set placed near the bow of the ship reveals the angle of reflection from the sea bottom of the sound of the propeller. Knowing the length of the ship and the angle of reflection, the pilot uses his knowledge of geometry to calculate the depth of the water.

The height of this plane above the sea is shown by the barometric altimeter. But the height above the land surface, whether mountain or valley, is indicated by sound reflection in the sonic altimeter.

Official U. S. Navy Photograph

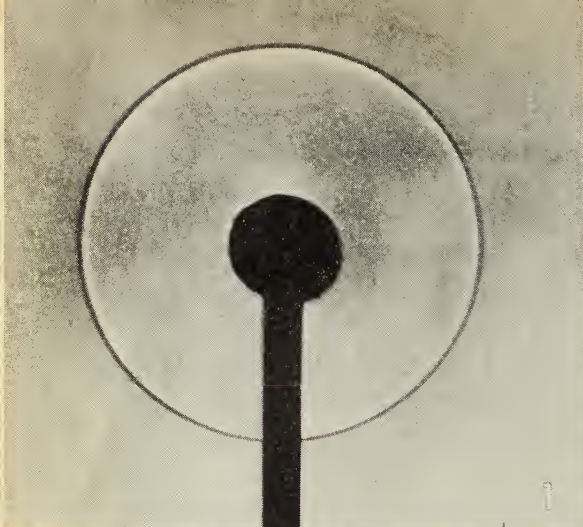


WHAT HAPPENS WHEN SOUNDS ARE REFLECTED

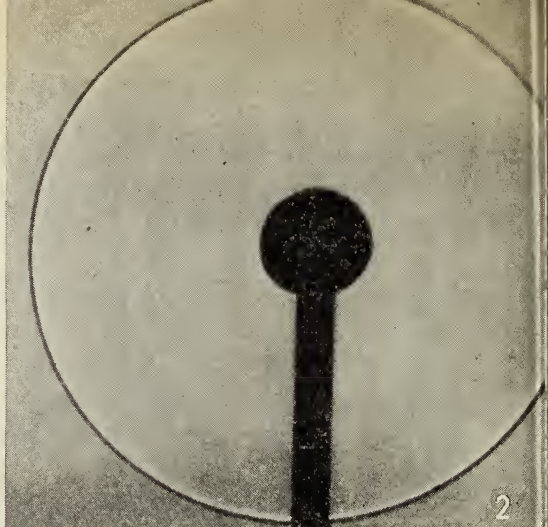
Echoes used to find the altitude of an airplane in absolute altimeters for airplanes. Pilots commonly make use of echoes to determine the height of an airplane above the level of the ground. The altimeter, as we recall, indicates only the distance above sea level and hence does not show how far the airplane is from the ground. In other words, it does not indicate the clearance. To overcome this difficulty, the pilot uses two special types of altimeters, known as absolute altimeters. One of these altimeters is the sonic altimeter and the other, which will be described later, is the radio altimeter.

The sonic altimeter makes use of reflected sound waves. It consists of a source of sound and a device for measuring the time interval between the emission of the sound and the reception of the echo. This time interval multiplied by speed of sound at a given temperature and divided by two will give the distance between the airplane and the ground. The character of the echo will also indicate something about the nature of the ground beneath the airplane. The efficiency of the sonic altimeter is limited by the interference of the noises of the airplane motors and propellers that make the echoes hard to hear. It is also limited because the speed of the airplane is too near the speed of sound. Sound travels about 1100 feet per second. If the airplane is about that height above the ground, it will take two seconds for the echo to get back to the airplane. In that time the modern airplane travels over 800 feet, and the character of the ground and consequently the airplane clearance may change a great deal in that distance. Because of the simplicity of its method and the inexpensive instruments required, the sonic altimeter is used on smaller airplanes. The radio altimeter, which will be explained in a later unit, is quite complex and requires expensive instruments. It is used on larger aircraft.

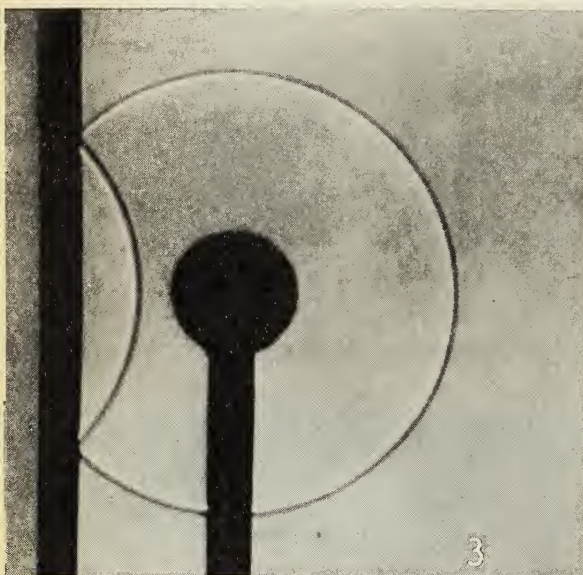
Reverberation. Reverberation is the repeated reflection of sound vibration. It differs from an echo in that an echo and the original sound are heard separately. If reverberation in auditoriums is too prolonged it produces a confusion of sounds and therefore



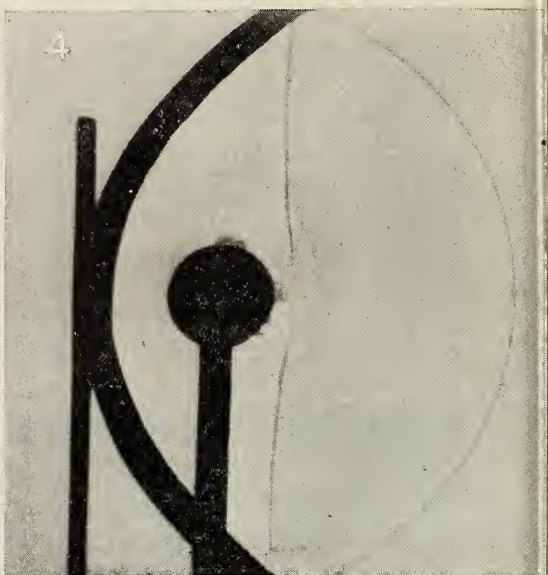
1



2



3



4



5

(Courtesy of Professor A. L. Foley, Indiana University)

PHOTOGRAPHS OF SOUND WAVES

The wave originates in an electric spark behind the middle of the round black disk.

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causes trouble. If, for example, there is too much reverberation, some of the speaker's words may still be sounding while others are being spoken. This is why sometimes, although the voice of the speaker seems loud enough, his words are not heard distinctly. On the other hand, if a room has too little reverberation, the sound seems dead, and that is especially bad for music. Since reverberation is due to reflection, it must be controlled by changes in the reflecting surfaces. This may be done by placing rugs on the floor or covering the walls with materials that have good absorbing properties. A large audience is an effective absorber of sound. Acoustical properties of rooms and auditoriums are an important consideration in architecture. Modern research work in this field has progressed so far that a room may be designed to have almost exactly the degree of reverberation desired. A visit to a modern radio broadcasting studio will make it clear how acoustical problems have been solved.

Can sound waves be seen? Photographs have been taken of sound waves. The illustrations on page 418 show some of the photographs taken by Professor A. L. Foley of the University of Indiana. Photograph (1) shows a spherical sound wave; (2) shows the same wave 0.00077 second later; (3) shows a wave reflected from a plane surface with curvature unchanged; (4) a wave reflected by a parabolic reflector, showing the wave to be a plane. Photograph (5) shows a wave reflected from and passing through a lens filled with sulfur dioxide. We see, first, parts of the original wave on the right; second, the wave reflected by the convex surface of the lens with increased curvature; third, the wave transmitted through the lens, and its curved wave front changed by the lens, due to refraction. Photography of sound waves was used by Professor Sabine of Harvard in the analysis of the acoustics of an auditorium.

Can sound waves be bent? Sound waves are refracted, or their direction is changed, if they pass into a medium of different density from that in which they have been traveling. Photograph 5,

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in the illustration on page 418, shows the effect produced on the wave front if it passes through sulfur dioxide gas. If any other gas had been used with a density greater than air, a photograph would show a change in the wave. If the lens had been filled with a gas lighter than air, the waves would diverge, or spread out, more after passing through than before.

The passage of sound waves through layers of air of different density causes them to rise in some places and descend in others. This accounts for the fact that the sounds that are sometimes heard at great distances are not heard at points nearer the source. At the bombardment of Antwerp in 1914 there was a soundless zone between distances represented by a circle of 60-mile radius and a circle of 90-mile radius. Beyond the 90-mile circle the sound of the bombardment was heard. The sounds of a fog siren are sometimes not heard by vessels in certain zones though heard distinctly by vessels farther away. Refraction of this sort seems to be due to layers of air that differ in density because of differences in temperature.

Forced vibration. All freely vibrating bodies have a natural period of vibration. Experiments with the pendulum showed that when gravity alone acts upon it, the period for a pendulum of a certain length is always the same. Other examples of freely vibrating bodies with certain periods that depend upon the properties of the bodies are the tuning fork and the violin string. Bodies can be made to vibrate in other than their natural period by the application of some periodic force. For example, a table is made to vibrate by pressing the base of a vibrating tuning fork against the top of the table. The period of vibration of the table is not its natural period but that of the tuning fork. Such vibrations are called forced vibrations. Other examples of forced vibration are the action of the sounding board of a piano and the body of a violin.

Sympathetic vibration or resonance. Let two similar balls be suspended by strings of exactly the same length from a small rod that is clamped at one end so that it is horizontal, as shown in

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Figure 164. These two balls so suspended are pendulums of the same natural period. Now let one of the balls be set in vibration. The other ball, on account of the small disturbances carried through the rod, will be set in vibration. This is an example of sympathetic vibration. Such examples are common. A swing can be started by small impulses, and if these small impulses are timed to the free natural vibration of the swing, it will be set into wide vibrations. A spring diving board and even a bridge can be set into wide vibrations by impulses of the same frequency as the natural vibrations of the body. For this reason, soldiers on the march break step when crossing a light bridge for fear that the bridge may collapse. Why? Such sympathetic vibrations occur widely in sound, light, and electricity. The fundamental principle is always the same; small impulses produce large vibrations if they are of the same frequency as the natural period of vibrations of the vibrating body. These occurrences are very frequent in sound; and so the name *resonance* is applied to them, whether set up by sound waves, electric waves, or any other kind of periodic disturbance.

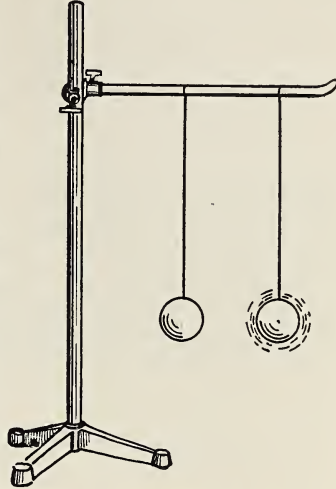


Fig. 164. Sympathetic vibrations continue after first vibrating body is deadened, as shown here.

Resonance by tuning forks. Let two mounted tuning forks that have exactly the same frequency be placed some distance apart with the open ends of their resonators facing each other. Strike one fork lightly with a soft mallet. After it has been vibrating a few seconds, stop its vibrating by touching it with the hand. Then the other fork will be heard. The second fork has been set in vibration by the impulses sent out by the first fork. The second fork, however, will not be set in vibration if its period is not the same as the first. This can be shown if a penny is fastened with

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wax to one of the prongs of the second fork, thus changing the frequency of the fork. If the first fork is sounded and quenched, no sound will be heard from the second fork. The reason is that, if the forks are not of the same natural period, the impulses will be applied in such a way as to start the second fork to vibrating a little at first, then to oppose its vibrations, alternately helping and opposing, but never giving it enough amplitude to cause it to be heard.

Resonance in air columns. If the ear is placed near a mounted tuning fork, it will be found that most of the sound comes from the open end of the box rather than from the fork. It may be noticed also that forks of high pitch are mounted on shorter boxes than are those of lower pitch. The effect in such a case is not simply resonance but resonance plus an amplification of the tone. To understand the relationship of the length of the resonating air column, the frequency of vibration of the fork, and the reason for the loudness of the tone, it is necessary to study the interaction between the waves sent out by the fork and those traveling back and forth in the box or tube.

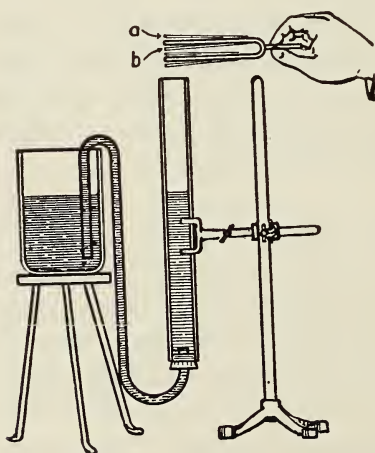


Fig. 165. Apparatus for measuring the ratio of sound-wave lengths set up by a tuning fork to the length of the resonating body.

Closed tubes. Suppose a closed tube is arranged as shown in Figure 165. By raising or lowering the tube the water rises or falls and thus adjusts the height of the column of air. If a sounding tuning fork is held over the mouth of the tube, resonance will be noted between the tuning fork and the air column, provided that certain phenomena take place with reference to condensation in the tube. The resonance occurs if the condensation starts down the tube when the



After striking the tuning fork on the left with the mallet, the student stops the vibration and listens for the sympathetic vibration of the tuning fork on the right. If its period of vibration is the same as that of the other fork, a tone will be heard.

prong of the fork leaves position *a* in Figure 165 and returns to the mouth of the tube just in time to join and reinforce the condensation upward as the prong leaves position *b*. The wave goes twice the length of the air column while the prong of the fork is performing half of a complete vibration. It travels once the length of the air column while the fork is making a quarter of a vibration. Since the fork sends out one wave in each complete vibration, the length of the air column must be a quarter of the wave length of the wave sent out by the fork.

To account for the loudness of the tone coming from the tube, it is necessary to know that when the condensation that has been reflected from the water reaches the open end of the tube some of its energy is reflected into the tube to travel back and forth many times. Now, when a condensation is reflected at the open end of the tube, it becomes a rarefaction. If the tube is in resonance with the fork, this rarefaction starts down the tube just as another rarefaction is started down the tube by the upward motion of the prong. The two rarefactions reinforce each other.

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In the same way a rarefaction is changed at the open end of the tube into a condensation that reinforces an incoming condensation. After such reinforcements, a wave of large amplitude is set up in the tube, accounting for the loud tone.

Resonance in longer closed tubes. In the preceding paragraphs the necessary condition for resonance is shown to be the adjustment of the length of the air column above the surface of the water until the wave traveling down the tube and up again reinforces the wave just starting from the tuning fork. If the total path of the wave in the tube is now increased one whole wave length, the reflected waves will again reinforce those being sent out by the fork. If the length of tube is increased by one-half a wave length, the path of the waves in the tube is increased by a whole wave length, since the waves traverse the tube once going down and again going up. A second point of resonance can then be found if the length of the air column is three-quarters of a wave length. It should be evident, also, that lengths of the air column of five-quarters, seven-quarters, etc., of a wave length will result in resonance.

Open tubes. If a sounding tuning fork is held near one end of a tube that is open at both ends, resonance will be obtained if the length of tube is one-half the wave length of the tone emitted by the fork. This is twice the length of a closed tube that gives resonance with the same fork. If a tuning fork starts a condensation down an open tube, this condensation will be reflected from the open end as a rarefaction to be again reflected at the end near the tuning fork, but this time as a condensation. If resonance is to occur, this condensation must reinforce a condensation just sent into the tube by the tuning fork. Since the fork sends condensations into the tube one wave length apart, the entire path of the wave in the tube must have been a whole wave length also. The length of the tube is then one-half the wave length. Resonance will also occur if the length of the open tube is $\frac{2}{2}$, $\frac{3}{2}$, $\frac{4}{2}$, and so on, of a wave length.

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Why is condensation reflected as a rarefaction at the end of an open tube? To account for condensation reflected as a rarefaction at the end of an open tube, we must understand that when a condensation reaches the end of the tube it has a chance to expand. The effect of this expansion is the same as if it met there a medium of lesser density. To understand what happens when a sound wave strikes a medium of greater density and when it strikes a medium of lesser density, we must remember that a condensation is produced by the crowding together of the particles of the medium because of their swing in the direction of the movement of the wave, whereas a rarefaction is due to the swing of the particles in a direction opposite to that of the wave. What happens can be shown by mechanical means with the apparatus illustrated in Figure 166.

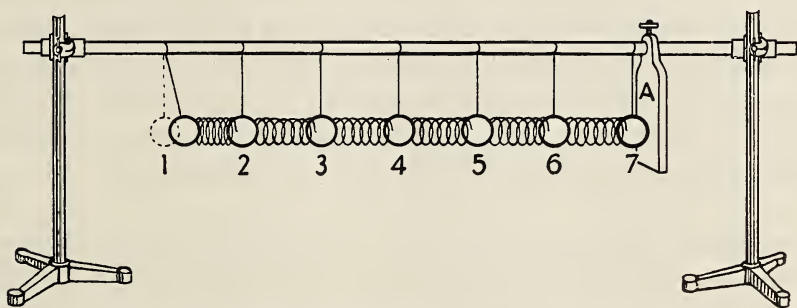


Fig. 166. Apparatus for demonstrating the condensation and rarefaction that occurs in a sound wave when the wave strikes a medium of greater or lesser density.

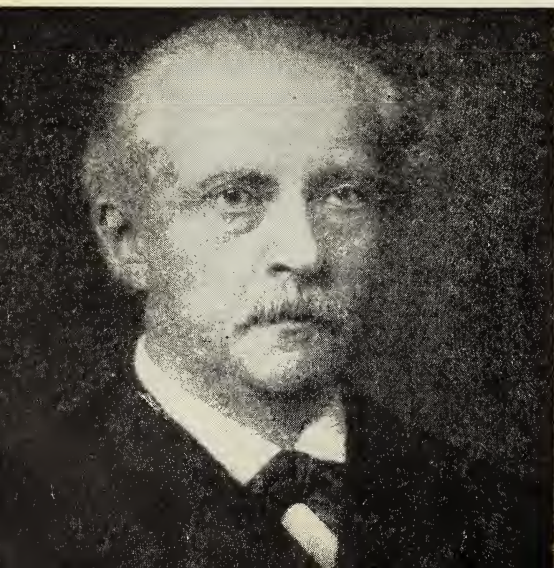
In this figure small balls are supported by wires and connected by coiled springs. If ball 1 is pressed suddenly toward the right, the spring between 1 and 2 is compressed and the motion is communicated to 2, and from 2 to 3, and from 3 to 4, and so on through the entire row. Thus an impulse corresponding to a condensation moves from 1 to 7, the motion of each mass in the same direction as the pulse. When the condensation reaches the solid A, which corresponds to the denser medium, ball 7 cannot move to the right, and the spring between 7 and 6, being compressed more than any of the preceding ones, recoils and throws ball 6 to

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the left, then 5 and 4, and so on back to the beginning. This, in terms of wave motion, means a condensation to the left. In other words, a condensation in meeting a denser medium is reflected as a condensation. In the same way it may be shown that a rarefaction in meeting a denser medium is returned as a rarefaction. In the following experiment we shall prove that a condensation may be returned as a rarefaction and a rarefaction may be returned as a condensation.

Let the body *A* be removed. Since there is no spring on the right of 7, that region may then be regarded as a rarer medium. Now if the ball is moved to the right as before, a condensation is sent down the row to 7. Since 7 has no spring on the right to be compressed, it will move farther to the right than any of the other balls, and will draw 6 after it. Ball 6 will draw ball 5, and so on back to ball 1. This pulse, causing the drawing apart of the balls, moves to the left, but the balls are moving to the right. This is the condition for a rarefaction, as we know, and we see that the condensation when it strikes a medium of lesser density will always be reflected as a rarefaction. In the same way it can be shown that a rarefaction is reflected as a condensation.

Resonators. There are other forms of resonators besides the long air column we have been studying. A sea shell held to the ear seems to be sounding because it is reinforcing the sound waves it has picked up. Of all the sound waves passing into it, only those that vibrate in unison with the air in the shell will be rein-



Helmholtz
(1821-1894)

Hermann Ludwig Ferdinand von Helmholtz devoted his life to the study of science. He made many important investigations in the whole field of science, but his greatest contribution is considered to be his work in the study of sound. He proved that the quality of tone depends upon the order, number, and intensity of the overtones that are part of the structure of a sound wave.

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forced. Helmholtz, a German scientist, made a set of spherical resonators as shown in Figure 167. They were of such different sizes that each would respond to tones of certain wave lengths. When we study musical sounds, we shall see how these resonators are used in the analysis of the structure of tones.

Resonance, wave length, and frequency. How can the wave length and the number of vibrations from any source be measured by resonance tubes? We have

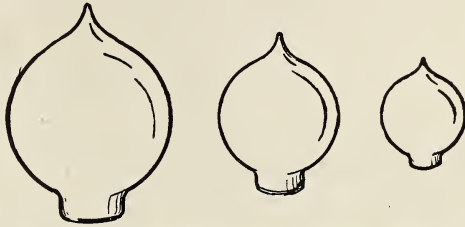


Fig. 167. Spherical resonators of different sizes.

seen that in a closed tube the first resonance is obtained when the length of the air column is one-fourth of the wave length. To find the wave length of any fork, we lower the water in the tube as in Figure 165 until we get the best resonance for the fork when it is vibrating at the mouth of the tube. The distance from the top of the tube to the water should be one-fourth of the wave length. However, this distance will be a little less than that because the effect of the tube persists beyond the mouth. Correction is generally made by the addition of 0.6 of the radius of the tube to the length measured. Since the distance thus obtained is the required one-fourth of the wave length, the wave length will be four times the distance. The amount of correction varies with the size and material of the tube and for that reason is rather uncertain. It is better to eliminate this error by finding a point farther down the tube for a second resonance. We have learned that this second resonance will be one-half a wave length farther down the tube. Since the error, because of the effect of the tube beyond the end of the tube, is found in both the first resonance and the second resonance lengths, it can be eliminated by subtraction. To find the frequency of the fork, we may use the equation $N = \frac{V}{L}$.

Example. Suppose we find by experiment that the length of the first resonance column is 15 centimeters and that the length of

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the second column is 48.6 centimeters. The temperature of the room is 21° Centigrade.

Solution. $48.6 - 15 = 33.6$ centimeters $= \frac{1}{2}$ wave length.

$33.6 \times 2 = 67.2$ centimeters = wave length.

Velocity at 0° = 33120 centimeters per second.

Velocity at 21° = $(21^\circ \times 60) + 33120 = 34380$ centimeters per second.

Frequency = $34380 \div 67.2 = 511.6$ vibrations per second.

Interference of sound waves. What happens when a condensation coincides with a rarefaction? We have seen in previous experiments that, when a condensation of one wave coincides with a condensation of another wave, the sound is much louder. We would infer from this that the loudness of the sound would be less when a condensation coincides with a rarefaction. To test this conclusion hold a vibrating fork near the ear and slowly rotate it. The sound in certain positions is much fainter than in others. When the tuning fork is vibrating, the prongs are either approaching each other, as shown in Figure 168 A, or moving apart, as shown in Figure 168 B, and condensations are sent out as indicated. In A a condensation is sent to the ear, while in B a

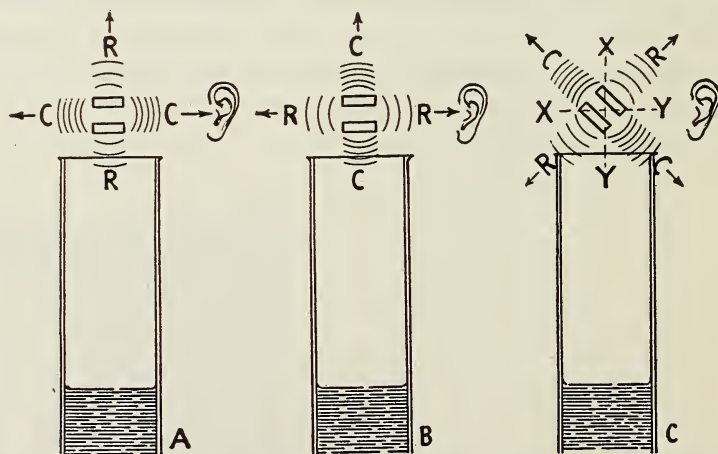


Fig. 168. Illustrations of the effects produced in the human ear and in a sounding chamber by variations in the occurrence of condensation and rarefaction.

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rarefaction is sent to the ear. In *C* the condensation and rarefaction coincide along the line *xy*, and interference is produced. When the fork is held so that the ear is on the line *xy*, the sound is extremely faint. No resonance will be produced by the column of air in the tube when the fork is in the position shown in *C*.

Beats. If we set into vibration two tuning forks of exactly the same frequency, the two sounds blend into one. Since the two forks have the same

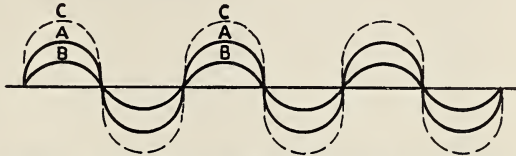


Fig. 169. Sound waves in the same phase reinforce each other to produce beats at regular intervals.

frequency and send out the same wave lengths, their waves unite in identical phases; that is, condensation coincides with condensation, and rarefaction with rarefaction as shown in Figure 169. The result of such coincidence, as we know, is reinforcement of the sound. Now if we change the frequency of one fork slightly by sticking a penny to one of its prongs, the sound of the forks swells and fades at regular intervals. These pulsations in loudness of the sound are called beats.

Let us suppose that one fork makes 256 vibrations per second and the other 255 per second. Then the first fork gains one full vibration on the other in one second, and the wave length sent out by the first fork is a little shorter than that sent out by the other. Since the first fork gains one vibration per second, the

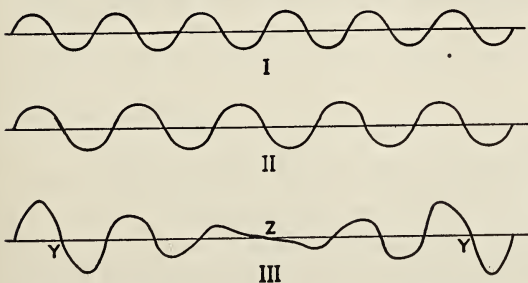


Fig. 170. Regular waves of different frequencies and an irregular wave produced by joining them together.

two waves will be in the same phase—that is, the condensation and rarefaction occur at the same time—once in a second, and they will be exactly out of phase once in a second. In Figure 170 two waves of different

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frequencies and wave lengths are represented by lines I and II. Line III represents the resultant wave that is set up when the forks are sounded together. At Y the sound swells out because the condensation and rarefaction are almost in phase. At Z the sound diminishes almost to silence since the two waves are in opposite phases, and a condensation of one wave reaches the ear at the same instant as a rarefaction of the other.

The number of beats per second is determined by the difference in the frequencies. For example, two forks of 256 and 255 frequencies would produce one beat per second. Beats are used in tuning two strings or any two sources of sound to the same frequency. The frequency of one of them is gradually changed so that the interval between beats gets longer and longer. When the beats disappear entirely, the two frequencies are exactly the same.

Beats and discords. When the beats produced by two sounding bodies are not more than five or six per second, the sound is not unpleasant. As the number of beats increases, the effect becomes more unpleasant. When there are about 30 beats present, the sound becomes most unpleasant, and we have discord. As the numbers increase beyond 30, the discordant effect diminishes.

ANSWER THESE QUESTIONS

1. Why is a speaker heard much better in a room than out in the open?
2. Under what conditions may a whisper be heard many feet away?
3. Why may the sound of music be heard better over water than over land?
4. How may the captain of a ship use echoes to tell how far he is from an iceberg?
5. How are echoes and reverberations controlled in a radio studio?
6. What is the use of a sounding board on a piano?
7. When will two sound waves produce silence?
8. How is the first resonance length of a closed pipe related to the wave length? of an open pipe?
9. Why are some pipes of a pipe organ longer than others?

HOW MUSICAL SOUNDS ARE PRODUCED

10. Why does one hear unusual sounds when he places his hand loosely over his ear?

11. What causes beats? When will two musical instruments produce beats?

12. What is the relationship between beats and discords?

SOLVE THESE PROBLEMS

A

1. When the temperature is 20°C. , how far away must the reflecting surface be before an echo is heard?

2. If a ship's captain hears his echo from an iceberg in 5 seconds, how far from the iceberg is he at a temperature of 0°C. ?

3. If the first resonance length of a closed tube is 6 in. and the second resonance length is 20 in., what is the wave length of the sound of the vibrating instrument?

4. What is the speed of sound if the first resonance length of a tuning fork with a frequency of 512 per second is 7 in. and the second resonance length is 20 in. in a closed pipe?

5. If two tuning forks of frequencies of 256 and 252, respectively, are sounded simultaneously, how many beats per second will be heard?

6. What is the wave length at a temperature of 24°C. if a man sings a note that has a frequency of 256 vibrations per second (middle C)?

B

7. If a closed tube 11.45 in. long responds to a note of a given frequency when the temperature is 15°C. , what is the frequency of the note if the tube is $1\frac{1}{2}$ in. in diameter?

8. If the tube is open in problem 7, what is the frequency of the note?

AREA FIVE

How Are Musical Sounds Produced?

At the beginning of this unit we saw how sticks of wood were made to produce first a noise and then music. We were told that it would be necessary for us to become familiar with some of the fundamental principles of sound before this could be explained.

EXPLORING THE WORLD OF SOUND

Now that we have these principles in mind, we can learn the physical differences between a musical sound and a noise. All sounds are either musical sounds or noises. A musical sound is produced by a body making regular vibrations and sending out waves at regular intervals. As was shown, noises may be made by the combination of musical sounds in a confused mass, the complexity of which is annoying. This is because we cannot analyze such sounds and determine their regularity. We demonstrated this fact by dropping a number of sticks all together and then dropping them one at a time.

The siren disk. Another way of showing the distinction between musical sounds and noises is by the siren disk shown in Figure 171. This consists of a metal disk with holes equally spaced in four concentric circles. In the outer circle are 48 holes, in the next 36, in the third row 30,

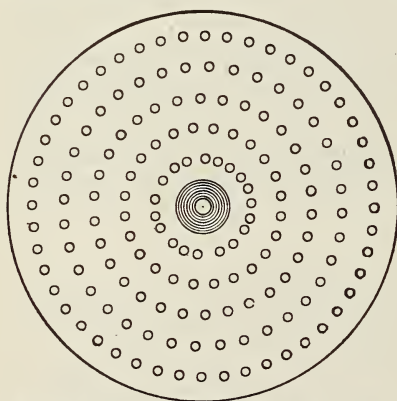


Fig. 171. Diagram showing the arrangement of the holes in an ordinary siren disk.

and in the fourth row 24. Inside these four rows is a fifth row with the holes unequally spaced. This disk is fastened at the center to a rotator and revolved at a constant speed. If a jet of air is directed from a tube against a row of equally spaced holes, a musical tone is produced. If the jet of air is then directed against the inner row of unequally spaced holes, the sound produced is no longer

an agreeable tone but a piercing noise, because the air jet now does not send out waves at regular intervals.

CHARACTERISTICS OF TONE

Intensity, pitch, and quality. All differences among musical tones may be expressed in terms of intensity, pitch, and quality. It is common knowledge that middle C on a piano may be struck

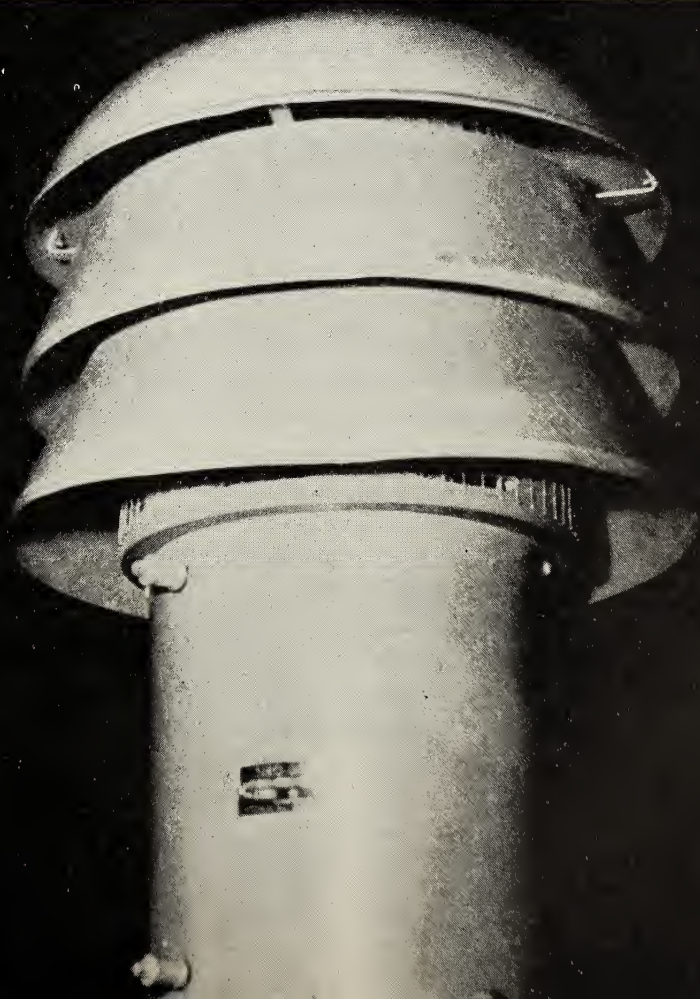
HOW MUSICAL SOUNDS ARE PRODUCED

softly or strongly to give the desired intensity. If the key next to middle C is struck there may be the same intensity as from middle C, but the pitch is higher or lower. If C is sounded on a piano and then on a violin the tones may have the same intensity and the same pitch, but they differ in quality.

Intensity. If a string on an instrument is struck, bowed, or plucked strongly, the amplitude of the vibration can be seen to be greater than when it is disturbed more gently. This has been mentioned before, and it has been established that in any particular case the intensity is proportional to the square of the amplitude.

We have all heard the warning voice of the air-raid siren. Sounds produced by the siren shown in the photograph below are transmitted for several miles.

Ewing Galloway



EXPLORING THE WORLD OF SOUND

Pitch. The pitch of a tone depends upon the number of waves sent out per second. Since these waves are set up by some vibrating body, the pitch depends upon the rate of vibration of the body, or the frequency. This may be shown by the siren disk, Figure 171. If a stream of air is directed against the inner row of 24 regularly spaced holes, a musical note is produced. The jet of air in passing through the holes is broken at regular intervals. The number of vibrations per second must be equal to the product of the number of holes and revolutions per second. If the speed is kept constant, the outer row of 48 holes gives a sound of twice the frequency given by the row of 24 holes. The tone is an octave higher. Now if the stream of air is directed successively against each row of the concentric circles, tones whose frequencies bear the relation of 4, 5, 6, and 8 are produced. Or, if the stream of air is directed against the outer row and the speed is increased, the pitch of the tone rises. Such experiments show that pitch depends on the number of vibrations sent out per second.

From the equation $N = \frac{V}{L}$ on page 427 it is evident that, for an increase in N , the number of vibrations per second, there must be a decrease in L , the wave length. The wave length of a tuning fork of 512 vibrations is exactly one-half the wave length of a tuning fork of 256 vibrations.

The Doppler effect. Why does the pitch of the whistle on a locomotive change as it passes the listener? When the distance from the vibrating body to the ear remains the same, the pitch of the tone coming to the listener does not change. But if the distance changes, as when the listener is moving either toward or away from the vibrating body, or it is moving either toward or away from him, a change in the pitch occurs. When a train is rapidly approaching the listener, the pitch of the whistle is higher than if the train were not moving. When it is receding, the pitch is lower. Changes in pitch are noticed as two automobiles pass each other with horns sounding. This apparent change in the pitch is called the Doppler effect, after its discoverer.

HOW MUSICAL SOUNDS ARE PRODUCED

When the ear and the source of the sound are at rest, the ear receives a fixed number of waves per second. But when the source of the sound is approaching the ear, it has the effect of increasing the number of wave lengths received per second and the pitch rises. When the sound is receding, the effect is to decrease the number received per second and the pitch is therefore lowered.

Quality of sounds. The third characteristic of a musical tone is that by which we may distinguish a tone of particular pitch when sounded by one instrument from the tone sounded by a different instrument. For example, if middle C is sounded simultaneously on a piano, violin, and cornet, the pitch is the same in all three cases and the loudness of the three sounds may be the same. But we can easily distinguish the sound of the piano from that of the violin or cornet. The sound of the human voice differs in quality in different individuals. The difference in quality is due to the fact that musical sounds generally result not from simple vibrations but from a blending of many vibrations caused by the sounding body vibrating simultaneously as a whole and in parts. The vibrations of the body as a whole produce the fundamentals, and the vibrations of the parts produce overtones. The vibrations of the body as a whole and the vibrations of the parts blend to give a complex form to the wave sent out by that particular instrument. The discussion of the production of overtones by different types of musical instruments will be taken up in our study of those instruments. It is sufficient to say here that the quality of a musical sound is due to the number and relative strength or predominance of the overtones present in the tone.

Limits of audibility. The smallest number of vibrations per second that will affect the average ear is about 16. The vibration rate of the lowest tone on a piano is 27. Some ears are not sensitive to this tone. The highest frequency used in music is about 4000, but the highest frequency audible is about 40,000 per second. However, many people cannot hear this. The upper limit for the average ear is about 20,000 vibrations per second.



From left to right the notes of the forks are do, mi, sol, do', or C-256, E-320, G-384, and C'-512. Vibrating together, the forks produce a major chord.

MUSIC

Music, as we have been told, is a combination of tones that is pleasing to the ear. In this sense of the word, music is a succession of sounds or of combinations of sounds whose vibration frequencies combine without clashing. In another sense of the word, music is a succession of tone combinations designed to convey to the listener the ideas and moods of the composer. The composer may feel that discords are necessary for the desired effect, for contrast, or to heighten the beauty of a following sequence of harmonious chords. Musical compositions, however, are constructed on definite rules of harmony and the theory of music. We will now examine the basic laws of the musical scale and combinations of scale tones.

A major triad. If two tuning forks of 256 and 512 vibration frequencies are sounded together, the ratio of vibration is 1 to 2 and the sound is pleasing. If the three forks C, E, and G are sounded

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together, the combination is also pleasing. The relative frequencies are 4, 5, and 6. Any three tones whose frequencies are 4, 5, and 6 when sounded together are harmonious, and the combination is called a major triad. For example, forks G (384), B (480), and D' (576), or F ($341\frac{1}{3}$), A ($426\frac{2}{3}$), and C' (512) might be used.

A major chord. If four forks C, E, G, and C', which have relative frequencies of 4, 5, 6, and 8, are sounded together, they produce a very pleasant combination of tones. This combination is called a major chord. A major chord is produced when the octave above the first note of a major triad is sounded with the three notes of the triad. G, B, D', and G' when sounded together form a major chord. This is also true of F, A, C', and F'.

The preceding experiments have shown that the most pleasing combinations of tones are those that correspond to very simple vibration ratios. These combinations were recognized long before anything was known about the frequencies of tones or the ratios of their vibrations. Early in the musical development of the race, people sang tunes and played musical instruments. The scientific study of music that gives mathematical ratio to the combinations of tones is a very much later development.

The diatonic scale. The next step was the formation of a musical scale. In building a musical scale, use is made of a range of tones, the highest of which is an octave higher than the lowest. The simplest musical scale used is called the major diatonic scale. The following tabulation shows the notes arranged to form the diatonic scale:

Letters.....	C	D	E	F	G	A	B	C'	D'
Syllables.....	do	re	mi	fa	sol	la	si	do'	re'
Relative vibrating numbers.....	24	27	30	32	36	40	45	48	54
Ratio of vibration.....	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2	$\frac{9}{4}$
Interval.....	.....	$\frac{9}{8}$	$\frac{10}{9}$	$\frac{16}{15}$	$\frac{9}{8}$	$\frac{10}{9}$	$\frac{9}{8}$	$\frac{16}{15}$	$\frac{9}{8}$

Inspection of the table shows that the musical sequence of tones forming the diatonic scale must have the ratios 1, $\frac{9}{8}$, $\frac{5}{4}$,

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$\frac{4}{3}$, $\frac{3}{2}$, $\frac{5}{3}$, $\frac{15}{8}$, 2, and $\frac{9}{4}$. The ratio of vibration rate of each note in the octave is the ratio of that note to the first note. The interval is the ratio of each note to the next lower note in the octave. There are three different intervals shown: $\frac{9}{8}$, $\frac{10}{9}$, and $\frac{16}{15}$. Musicians speak of the intervals $\frac{9}{8}$ and $\frac{10}{9}$ as whole steps, and the interval $\frac{16}{15}$ as a half-step. The interval between the first note and the fifth is called a perfect fifth and that between the first and the third a major third.

For the first note of the octave any frequency may be taken; but the others must have the ratios to the first as shown in the table. For example, if we give C the number 256, the frequency of D is $\frac{9}{8}$ of 256, or 288, and E is $\frac{5}{4}$ of 256 or 320, which will give the following rates for the octave in the key of C:

C	D	E	F	G	A	B	C'
256	288	320	$341\frac{1}{3}$	384	$426\frac{2}{3}$	480	512
1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2

The chromatic scale. Any other note than C may be taken as the keynote and the other notes formed by multiplying the keynote by the ratio of vibrations used above for the key of C. For example, suppose the scale is formed by using the note D as the keynote and multiplying its frequency by $\frac{9}{8}$, $\frac{5}{4}$, $\frac{4}{3}$, $\frac{3}{2}$, $\frac{5}{3}$, $\frac{15}{8}$, and 2. The frequencies for the notes so obtained are shown in comparison with those in the key of C in the following table:

Note	C	D	E	F	G	A	B	C'	D'
Key of C..	256	288	320	$341\frac{1}{3}$	384	$426\frac{2}{3}$	480	512	576
Key of D..	....	288	324	360	384	432	480	540	576

Differences in the frequencies of the notes E, F, A, and C' in the two keys are shown. The differences in the notes F and C' are considerable, so when musicians play in the key of D, they introduce two new notes F# (F sharp) and C# (C sharp). As the differences in the notes E and A are comparatively small, no notes are introduced. The new note F# is formed by taking $\frac{25}{24}$ of the

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frequency of F and the new note C $\sharp$ by taking $\frac{25}{24}$ of the frequency of C. In general, the sharp of a note is obtained by taking $\frac{25}{24}$ of the frequency of the note. For example, the frequency of F $\sharp$ would be $\frac{25}{24}$ of $341\frac{1}{3} = 355\frac{5}{9}$ and the frequency of C $\sharp$ would be $\frac{25}{24} \times 512 = 533\frac{1}{3}$. These notes are not far from the frequencies of F and C in the key of D.

Sometimes in constructing a scale a note must be lowered or flattened. The frequency of a flat is $\frac{24}{25}$ of the note from which it is derived. Sharps and flats are called chromatic semitones. In practice chromatic semitones are introduced when whole-step intervals occur. In the chromatic scale both a sharp and a flat are necessary for each whole step, because the sharp of one note does not have the same frequency as the flat of the next higher note. For example, the frequency of C $\sharp$ is $\frac{25}{24}$ of $256 = 266\frac{2}{3}$, while the flat of D, or D $\flat$, is $\frac{24}{25}$ of $288 = 276\frac{1}{2}$. The chromatic scale consists of eight regular notes of the diatonic scale and ten semitones for the five full-tone intervals.

The even-tempered scale. If the scales were built in all the possible keys and a new note introduced for each difference, an octave would require 70 notes. It would be possible for all these gradations of tone to be produced on the violin by a skillful artist. Similarly, they might be produced on the trombone or by the human voice. In the case of an instrument like the piano, however, which has a fixed keyboard, to do this would require 70 keys to the octave. The difficulty in learning to play such an instrument makes it impracticable. To avoid such a keyboard, musicians have agreed upon a compromise scale called the even-tempered scale. In this scale the octave is divided into 12 equal intervals. Since the frequency of the upper note of the octave is twice that of the keynote, the ratio of any note to the next lower is taken as the twelfth root of 2 ($\sqrt[12]{2}$) which is 1.05946. On the piano this scale is represented by the eight white and five black keys in the octave. Each black key represents both the sharp of one note and the flat of the next note above. In this scale the vibration rate of any tone can thus be obtained by

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the multiplication of the frequency of the preceding tone by 1.05946. For example, taking middle C as 256, the next note represented by a black key is either C $\sharp$ or D $\flat$ and is $256 \times 1.05946 = 271.22$, and the frequency of D is 287.3. A comparison of the frequencies of the notes in the chromatic and even-tempered scales is shown in the following table:

CHROMATIC SCALE		EVEN-TEMPERED SCALE	
Note	Frequency	Note	Frequency
C.....	256	C.....	256
C $\sharp$	266.1	C $\sharp$ or D $\flat$..	271.2
D $\flat$	276.5	.....	.....
D.....	288	D.....	287.3
D $\sharp$	300	D $\sharp$ or E $\flat$..	304.4
E $\flat$	307.2	.....	.....
E.....	320	E.....	322.5
F.....	341.3	F.....	341.7
F $\sharp$	355.5	F $\sharp$ or G $\flat$..	362
G $\flat$	368.6	.....	.....
G.....	384	G.....	383.6
G $\sharp$	400	G $\sharp$ or A $\flat$..	406.4
A $\flat$	409.6	.....	.....
A.....	426.7	A.....	430.6
A $\sharp$	444.4	A $\sharp$ or B $\flat$..	456.2
B $\flat$	460.8	.....	.....
B.....	480	B.....	483.3
C'.....	512	C'.....	512

Standard pitch. The standard middle-C tuning forks used in physics laboratories have a frequency of 256. This makes A have a frequency of $426\frac{2}{3}$. The international pitch gives A a frequency of 435. In the pitch adopted by the American Federation of Musicians, A has 440 vibrations per second.

MUSICAL INSTRUMENTS

Musical instruments are classified as stringed, wind, and percussion. These terms refer to the nature of the vibrating body producing the sound: strings or wires, air in tubes of metal or wood,



The instrument in this photograph is a sonometer. By touching the vibrating string, the student finds the note that corresponds with the note of the tuning fork.

and reeds, plates, or membranes. Can you name some musical instruments that do not come under this classification?

Stringed Instruments

To study the factors that affect the frequency of vibrating strings, a sonometer is used. It is a hollow wooden box upon which are stretched at least two piano strings between fixed bridges at the ends. A spring balance or a weight is used to determine the stretching force acting on each string. The string length is varied by a movable wooden bridge.

The laws of vibrating strings. With the sonometer and a number of tuning forks we can easily investigate the various factors that determine the pitch of the tone given by a vibrating string. If the length of a string is adjusted until the tone is the same as

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given by a fork of pitch C—256 vibrations per second—and if the length is then changed by means of moving the bridge until the tone is C'—512 vibrations per second—the second length will be half the first. This suggests the law that frequency is inversely proportional to length if other factors are kept constant. If the length of the string is kept constant while the tension is adjusted so as to make the tone of the string equal first to C, then to C', the second tension will be four times the first, indicating that pitch is proportional to the square root of the tension. By the use of wires of various diameters and materials we can show that, other factors being constant, pitch is inversely proportional to the square root of the mass per unit length of string.

These laws are illustrated clearly by the strings in a piano. If the student will examine the strings, he will find that the high-pitched notes come from fine, short, and tightly stretched wires, and the bass notes come from very coarse, long, and loosely stretched wires. On the violin, the strings, as in the piano, are graduated in thickness from the highest to the lowest. The correct pitch of each string in relation to the others is secured by adjustment of the tension.

Problem: Law of length. If the length of a string in the sonometer is 70 centimeters when it is in tune with the C fork, to what length must it be shortened so that it will produce the note G?

Solution. The C fork has 256 vibrations per second and G has a frequency of 384. Then $256 : 384 :: x : 70$,

$$\text{or } \frac{256}{384} = \frac{x}{70} \text{ or } \frac{2}{3} = \frac{x}{70} \quad 3x = 140. \quad x = 46\frac{2}{3} \text{ centimeters.}$$

Problem: Law of tension. A tension of nine pounds produces C on one of the sonometer strings. If the length is kept the same, what force must be applied to the string to produce the note of G?

Solution. C has a vibration frequency of 256 and G a frequency of 384. Then $256 : 384 :: \sqrt{9} : \sqrt{x}$,

$$\text{or } \frac{256}{384} = \frac{\sqrt{9}}{\sqrt{x}} \text{ or } \frac{2}{3} = \frac{\sqrt{9}}{\sqrt{x}} \text{ or } \frac{4}{9} = \frac{9}{x}.$$

$$4x = 81. \quad x = 20.25 \text{ pounds.}$$

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How a string vibrates. Let a piece of rubber tubing about 10 inches long be fastened at one end and the other end held in the hand. If the hand is moved up and down in the proper way, the tube will vibrate as a whole as shown in

Figure 172, *a*. More rapid movement of the hand will break the vibration into two, three, and four segments, as shown in Figure 172, *b*, *c*, and *d*. The parts that are moving are called loops, and the points of little or no motion

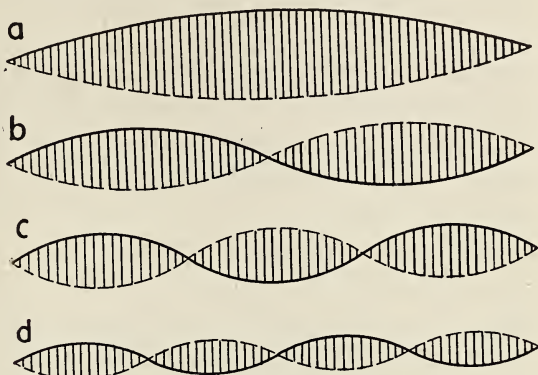


Fig. 172. Rubber tubing vibrated at different speeds.

are called nodes. There is little or no motion at the nodes because the advancing and reflected waves act in opposite directions and so tend to neutralize each other.

Figure 173 shows a fine cord about four feet long, one end of which is attached to the prong of a tuning fork and the other end to a weight. Near the end attached to the weight is a pulley that permits the cord to move freely. By adjusting the weight, the string may be made to vibrate as a whole or in two or three segments. When a cord vibrates in two parts it vibrates with twice the frequency that it does when vibrating as a whole,

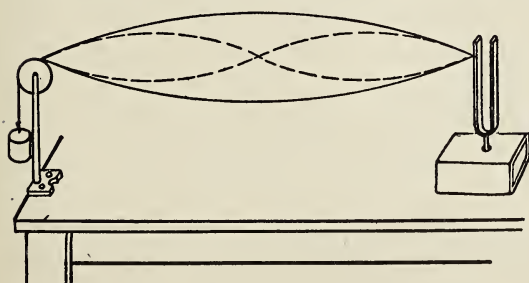


Fig. 173. Sound-wave vibrations set up in the tuning fork cause the string to vibrate at regular intervals.

and when it vibrates in three parts it vibrates with three times the frequency, and so on. The pitch of a cord vibrating as a whole is the lowest it can produce and is called the fundamental. When a cord vibrates

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in two parts, the tone has twice the frequency and is called the first overtone. When a cord is vibrating in three parts, its tone has a frequency of three times the fundamental. This is called the second overtone, and so on.

Fundamental tones and overtones of a vibrating string. The preceding experiments reveal the fact that a string may vibrate either as a whole, or in segments separated by points of no vibration or nodes. With a sonometer we may discover how these vibrations affect the tones produced. Let the string of a sonometer be plucked in the middle. This will cause it to vibrate as a whole. Note the pitch of the tone produced. This is the fundamental tone, the lowest pitch the string can produce. Now touch the middle of the string with the finger and pluck the string at one-fourth of its length. The tone produced is recognized as an octave higher than the fundamental, which is to be expected because the string is now vibrating in two parts and its frequency of vibration is twice as great. This is called the first overtone of the string. If the finger is touched at one-third of the string length from one end and the string plucked at one-sixth of its length, it will vibrate in three segments and its frequency will be three times as great. The tone is sol in the next octave, which is the second overtone. In the same way the string can be made to vibrate in four segments and produce the third overtone, or in five segments and produce the fourth overtone.

In the above experiments the string was made to produce the overtones by forcing it to remain at rest at certain points. Now let the string be plucked at one fourth of its length without touching it in the middle. The string is seen to vibrate as a whole and also in four parts. This proves that a string can be made to produce its fundamental and an overtone at the same time.

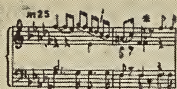
How the presence of overtones affects the tone. Let the wire of a sonometer be plucked first in the middle and the tone carefully noted, and then let it be plucked close to one end and this tone carefully noted. It will be noticed that while the two tones have

HOW MUSICAL SOUNDS ARE PRODUCED

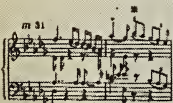
exactly the same pitch and may have the same loudness, there is a difference between them. The tone set up by the wire when it was plucked near one end has a richness and a fullness that the other tone lacks. This difference is related to what we call quality and is due to the number and prominence of the overtones present. As has been shown, the frequencies of the overtones of a string are simple and exact multiples of the fundamental such as 2, 3, 4, and 5. Such overtones combine with the fundamental to produce harmonious tones and for that reason are called harmonics.

Tone analysis. Helmholtz, with his resonators described on page 427, first analyzed complex sounds and gave proof that the quality of a tone is determined by the number and prominence of the overtones that are blended with the fundamental. He had a large number of spherical resonators made. Each resonator would respond to a note of some particular pitch. By holding these resonators to his ear successively while a musical note was sounding, he could pick out the fundamental and the overtones that were present. Then he put those constituents together and reproduced the original tone. He did this by assembling tuning forks with frequencies that corresponded to the fundamental and the overtone of the musical note, and sounded them simultaneously with the proper relative loudness.

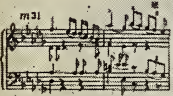
Sound waves and a gas flame. Another method of tone analysis is by the use of the manometric flame. The apparatus consists of a small box divided into two parts by an elastic membrane. On the left side is a tube with a mouthpiece. On the right are fitted a tube for the flame and a tube to the gas supply. When a sound enters the mouthpiece, the vibration of the air causes the membrane to vibrate. These vibrations alternately compress the gas and then permit it to expand, causing the flame to dance up and down when viewed in the revolving mirror. When no sound enters the box, a straight band of light is seen in the mirror. The sounding of a fundamental produces a series of zigzags in the line



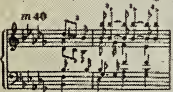
The voice of the tenor, Caruso, singing the syllable chi (kē) in the 26th measure of the sextette in Donizetti's opera, Lucia di Lammermoor. The words of the passage in Italian and English are as follows: mo chi? chi? (but who? who?)



The voice of the soprano, Tetrazzini, singing the syllable sa (sā) in the 32nd measure. The words of the passage are as follows: Vorrei piangere e non posso, m'abbandona, m'abbandona il pianto ancor. (I want to weep and cannot do so, tears abandon me still, abandon me still.)

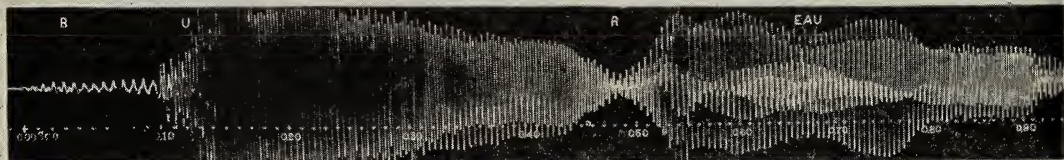


The voices of Tetrazzini, soprano, and Amato, baritone, in the 32d measure. The soprano is singing the syllable m'ab (m'āb) in the passage: Vorrei piangere e non posso, m'abbandono, m'abbandona il pianto ancor (I want to weep and cannot do so, tears abandon me still, abandon me still.) The baritone is singing the syllable nan (nān) in his words: spegnere non posso i rimarsi (allay my remorse I cannot ever).

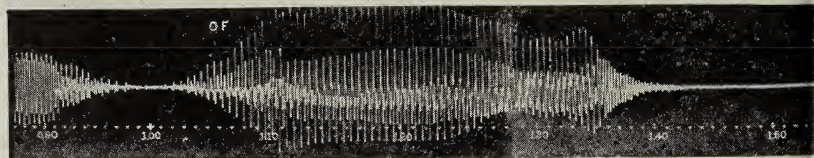


The voices of the entire sextette singing one syllable in the 41st measure. The soprano sings the syllable pos (pās), the mezzo-soprano the syllable cam (kām), the tenor the syllable sa (sā), the second tenor the syllable i (ē), the baritone the syllable non (nōn), and the bass the syllable in (ēn). In this measure, at the moment shown in the photograph, each singer is singing a different syllable in a different word and on a different note, but all in harmony.

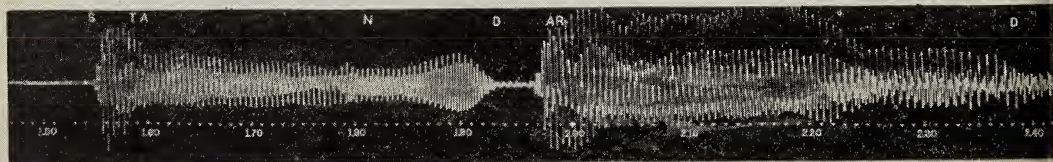
PHONODEIK PHOTOGRAPHS OF VOICE VIBRATIONS OF RENOWNED SINGERS IN THE SEXTETTE FROM LUCIA DI LAMMERMOOR. Photos and music from "The Science of Musical Sounds" by Dayton Clarence Miller, the Macmillan Co.



Sound vibrations of the word "bureau."



Sound vibrations of the word "of."



Sound vibrations of the word "standards."

PHOTOGRAPHS OF DR. MILLER'S VOICE VIBRATIONS PRONOUNCING "BUREAU OF STANDARDS."

Courtesy of Mrs. Dayton Clarence Miller and the Case School of Applied Science, Cleveland, Ohio

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that are all the same length. When overtones are sounded with the fundamental, the oscillations in the band of light are of varying length.

The phonodeik. Dr. D. C. Miller, formerly of the Case School of Applied Science, invented an instrument to photograph sound waves. This instrument, shown in Figure 174, is called a phonodeik. It has a thin diaphragm d covering one end of a resonator h . One end of a fine thread is attached to the diaphragm and the other end, after winding once around a spindle that supports a small mirror m , is attached to a spring s . Sound waves that strike the diaphragm set it into vibration.

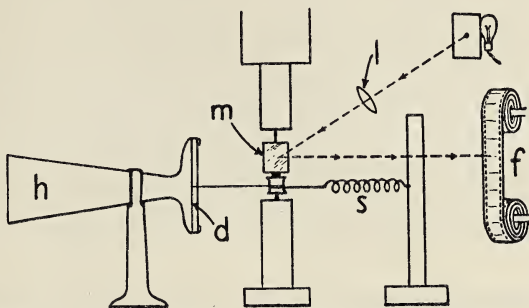


Fig. 174. Diagram showing essential parts of a phonodeik.

These movements of the diaphragm, communicated to the spindle by means of the thread, cause the mirror attached to the spindle to oscillate slightly, the amount of movement being governed by the amount of motion of the diaphragm. A beam of light is focused on the mirror by the lens l and is reflected by the oscillating mirror to a moving film f . The oscillating movement of the mirror causes variations in the reflection of the beam, and these variations are photographed on the moving film.

Photographs of sound waves taken by Dr. Miller with this machine are shown on the opposite page. The dotted line visible in each strip of film is a time line, the space between the dots representing one-hundredth of a second. The three strips shown for the pronunciation of "Bureau of Standards" are overlapping parts of a continuous strip. Examination of the time line will show that the pronunciation of the three words took two and one-half seconds.

EXPLORING THE WORLD OF SOUND

Wind Instruments

How are musical sounds produced in wind instruments? If we blow across the open end of the cap of a fountain pen, a musical tone is produced. The cap is a tube closed at one end and acts as a closed-tube resonator. Let us see how the sound is produced. Sounds are produced by vibrations. When we blow across the open end, we cause a condensation to travel down the tube. When this condensation returns to the mouth of the tube after reflection at the closed end of the tube, it pushes the air jet outside of the opening. This starts a rarefaction down the tube, which, after its return from the closed end, pulls the jet in again. In this way vibrations are set up in the air at the mouth of the tube. It is evident that the frequency of the vibrations depends on the length of the tube. Tones can also be produced by blowing across the end of an open tube such as a piece of glass tubing. Sound-wave action in an open tube was described on page 424.

Pitch and length of air column. Let a resonating column be set up and the water adjusted until it is in resonance with a 512 fork as shown in Figure 165 on page 422. Now let a stream of air be blown across the open end. If the air current is suitably directed, the pipe will emit a tone of the same frequency as the 512 fork. If we adjust the length of the air column so that it is in resonance with another fork of the diatonic scale, the air column will emit a tone of the same frequency as the latter fork. From this experiment we learn that the wave length of the tone produced is four times the length of the air column. We also learn that the frequencies of the tones produced are inversely proportional to the lengths of the air column. This means that if the length of the air column required to emit the note C is known, the lengths of the air columns to produce the other notes of the diatonic scale will be $\frac{8}{9}$, $\frac{4}{5}$, $\frac{3}{4}$, $\frac{2}{3}$, $\frac{3}{5}$, $\frac{8}{15}$, and $\frac{1}{2}$ of that length.

We have learned that for an open pipe the length of the air column is one-half the wave length of the tone for which it produces resonance. From this we infer that when suitably blown an open pipe will emit a tone having a wave length equal to twice

HOW MUSICAL SOUNDS ARE PRODUCED

the length of the pipe. This means that if the same pipe be blown as an open pipe and then as a closed pipe (by the hand placed across the end), its tone as an open pipe will be an octave higher than its tone as a closed pipe.

Types of wind instruments. Wind instruments with which tones are produced by vibrating air are organs, accordions, trumpets, bugles, clarinets, fifes, piccolos, saxophones, trombones, and horns. These instruments differ in the mode of excitation of vibration of the inclosed air column. The part of the instrument in which the vibration is excited is called the mouthpiece. Mouthpieces are of three types: (a) those in which the air is blown across a sharp edge or across an opening, as in an organ pipe or flute; (b) those in which the air is forced through an opening partly closed by a reed, as in the mouth organ; (c) those through which the air passes after it has been excited by the compressed lips of the performer, as in playing a cornet.

Overtones in pipes. If we blow gently on a pipe it will produce its fundamental. In our experiment with resonating columns, on page 448, the columns were emitting their fundamentals, the lowest tones they could produce. By blowing harder across the pipes we obtain tones of higher pitch. These tones are called the overtones. By varying the intensity a series of overtones may be obtained. We have seen how strings vibrate in segments to produce overtones. Overtones are also produced when air columns vibrate in segments.

Nodes and loops in pipes. The presence of nodes and loops in vibrating strings is described on page 443, where it is shown that the advancing and reflected waves formed nodes and loops, thus producing fundamentals and overtones. Figure 175 shows how the presence of nodes may be shown in the organ pipe by

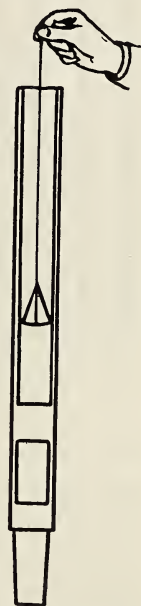


Fig. 175. Locating nodes and antinodes.

EXPLORING THE WORLD OF SOUND

lowering into a resonating pipe a small paper disk upon which are a few grains of sand. When the paper reaches a node, the point of least disturbance, the sand is undisturbed. When the disk reaches an antinode or loop, the point of greatest disturbance, the sand is violently agitated.

Figure 176 shows the nodes and antinodes in closed and open pipes. In a closed pipe there is always a node at the closed end. In pipe 1 we see the air column vibrating as a whole and emitting its fundamental. The length of the tube is one-fourth of the wave length of the tone. In pipe 2 there are nodes at the bottom and one-fourth of the way from the top. Since from one node to the next is one-half of a wave length, this tube is three-fourths of the wave length of the tone; which means the tone has three times the frequency of the fundamental. This is its first overtone. The air column in pipe 3 is five-fourths of a wave length of tone,

and its frequency is five times the frequency of the fundamental. The closed pipe can produce only those overtones whose frequencies are odd multiples of the fundamental.

Open pipes must have antinodes at the ends. Pipe 4 shows an open tube emitting its fundamental tone.

Here we see that the length of the pipe is one-half of the wave length of the tone. Pipe 5 shows the wave length of the tone emitted to be equal to the length of the pipe, and its frequency must be twice that of the fundamental. It is the first overtone. Pipe 6 shows the second overtone, the frequency of which is three times that of the fundamental. An open pipe can then produce all the overtones rather than just the odd ones that are produced by a

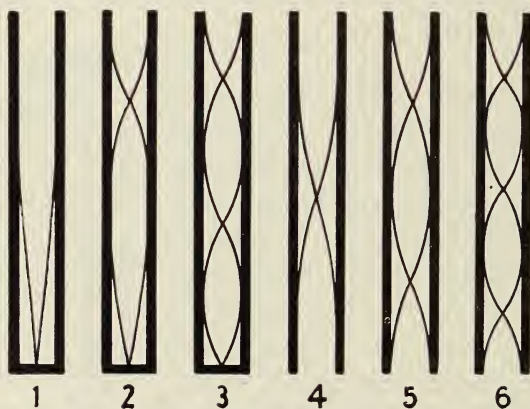
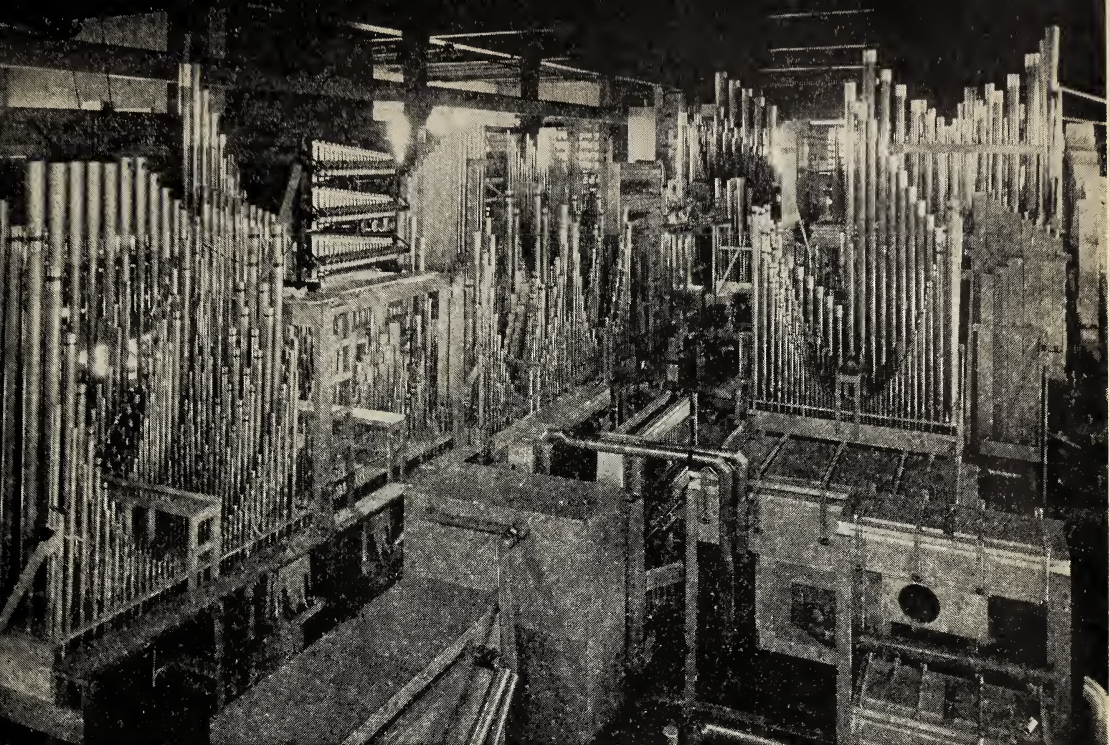


Fig. 176. Nodes and antinodes in closed and open pipes.



Ferdinand Hirsch

Rows of pipes of different lengths and diameters are tested at the factory for perfection of tone vibration before they are installed in the organs.

closed pipe. The quality of the tone of wind instruments depends, as in the case of stringed instruments, upon the number and prominence of the overtones. The prominence of the overtones is affected by the material of which the pipes are made. In some instruments extra air pressure causes overtones to predominate.

The air column in some wind instruments is made to vibrate by reeds or membranes set into the mouthpiece of the instrument. The human voice is an example of such an instrument. Its tones are produced by the vibration of a pair of membranes, one in each side of the throat, called the vocal chords. By change in the muscular tension on the chords the pitch of the voice is changed, and by change in the shape of the mouth the overtones are changed, and consequently the quality of the tone is changed. Well-known examples of reed instruments are the saxophone, clarinet, oboe, and bassoon. In these instruments the length of the air column can be regulated by holes or pistons.

EXPLORING THE WORLD OF SOUND

Percussion Instruments

Vibrating membranes. In some instruments the notes are produced by vibrating membranes. One example of such an instrument is the drum, in which the membrane, stretched tightly over the head of the instrument, is set into vibration by percussion.

Vibrating plates. The best illustrations of musical instruments in which vibrating plates are used are bells, chimes, and xylophones. In many such instruments certain overtones are very prominent and not in harmony with the fundamental. The discordant sounds produced are sometimes used deliberately for “musical” effect.

The Phonograph

The phonograph. A phonograph or “written-sound” machine reproduces sound that has been “written” on a surface of proper character. For recording sound a metal point is attached to a diaphragm by a lever system. As the sound waves make the diaphragm

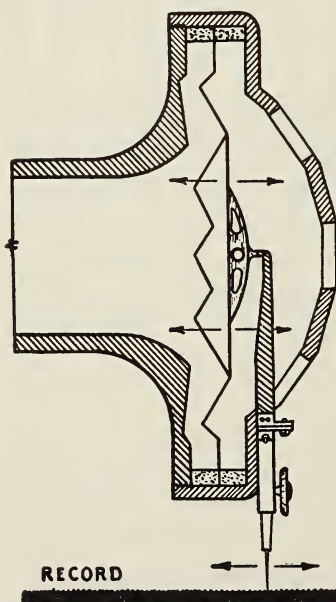


Fig. 177. Needle and diaphragm for reproducing recorded sound.

vibrate, the metal point traces a path on the revolving disk of wax or other appropriate substance. The disk is etched and an electrotype of copper is then made from it. From this electrotype manufacturers make any desired number of copies of the original by pressing hard rubber or other composite material into its surface. The sound is reproduced by using a needle that follows the groove that has been made in the record. The needle, as shown in Figure 177, is carried by a diaphragm, which is thrown into vibration similar to that of the original sound. The quality of the tone produced depends upon the needle used and the resonant properties of the instrument.

HOW MUSICAL SOUNDS ARE PRODUCED

ANSWER THESE QUESTIONS

1. When is a sound musical?
2. When is a sound noise?
3. Upon what does pitch depend?
4. How is the pitch of a person's voice changed?
5. Why does the pitch of an automobile horn change as it passes you?
6. Upon what does the intensity of sound depend?
7. Upon what does the quality of a musical sound depend?
8. What is a fundamental tone?
9. What is a major triad?
10. How is the diatonic scale formed?
11. What is a chromatic scale?
12. How is the even-tempered scale formed?
13. How are musical instruments classified?
14. What four factors determine the frequency of a vibrating string?
15. Why are bass piano strings made of heavy material?
16. Which is longer on a piano, the strings that produce high tones or those that produce low tones?
17. What are harmonics?
18. What kind of an instrument is made by human vocal chords?

SOLVE THESE PROBLEMS

A

1. If a tuning fork vibrates 256 times per second, what will be the frequency of one that is an octave higher?
2. Assuming that *do* has a frequency of 240 vibrations per second, construct a diatonic scale.
3. If a string 100 cm. long vibrates 288 times per second and the tension remains the same, how long should the string be to vibrate 512 times per second?
4. If a string stretched with a force of 100 lb. has a frequency of 512 vibrations per second, what will its frequency become when the tension is reduced to 64 pounds?

B

5. If a string 100 cm. long produces a C, what lengths of string will give each note of the major chord?
6. Determine the vibration frequencies of the first three overtones if C has 256 vibrations.

EXPLORING THE WORLD OF SOUND

7. An open organ pipe is 4 ft. long. Calculate the frequencies of the first three overtones. The temperature is 20°C .

8. The lowest tone on a piano has a frequency of 27. Calculate the length of an organ pipe that will give this tone when the temperature is 20°C .

9. Compare the frequency of a steel string 100 cm. long, whose density is 7.8 and tension is 36 kg., to a brass string 80 cm. long, density 8.5 under a tension of 64 kilograms.

SUMMARY

Sound is energy transmitted in the form of a rapid vibratory motion that produces a sensation through the ears. Sound is transmitted through matter as a medium, and therefore it cannot be transmitted through a vacuum. Sound travels 1089 feet or 331 meters per second in air at 0°C . As the temperature increases, the velocity of sound increases. Sound travels in longitudinal waves that are made up of condensations and rarefactions. The length of a sound wave is the distance from one part of one wave to the corresponding part of an adjoining wave. The term frequency of sound waves is used to designate the number of vibrations per second. The velocity of sound equals the product of the wave length and the frequency.

Intensity of sound is measured by the quantity of energy in the sound wave that passes through a surface of one square centimeter in one second. Intensity depends upon (a) the distance from the origin, (b) the amplitude of vibration, (c) the density of the medium, and (d) the area of the vibrating body. Loudness is the apparent strength of the sensation received through the ear. It depends upon the intensity of the sound wave that reaches the ear and upon the sensitiveness of the ear. Units of loudness are the bel and decibel.

Sound waves are reflected when they meet a medium that has a different density from the medium through which they already have passed. Echoes are reflected sound waves. Reverberation is repeated reflection of sound. Reflection of sound waves is controlled in rooms by covering the reflecting surfaces with sound-

absorbing material. When a body vibrates in periods other than its own, the vibrations are forced. When a body is caused to vibrate by the vibrations from another body that has the same natural period, its vibrations are sympathetic. Resonance is a result of the reinforcement of sound by sympathetic vibrations. When sound fades and swells at regular intervals, beats occur.

Music is any series or combination of sounds that is produced for the purpose of creating a pleasing effect upon the listener. Sounds have three properties; namely, loudness, pitch, and quality. Loudness depends upon the strength of the sensation received by the brain through the ear. Pitch depends upon the frequency of vibration. The quality of sound is due to the number and character of the overtones. The vibrations of a body as a whole produce fundamental tones, and the vibrations of the parts of a body produce overtones. The simplest musical scale is called the diatonic scale. The chromatic scale is formed by selecting any note as a key, applying the diatonic scale ratios to find the frequencies of the other notes of the scale, and introducing chromatic semitones. The even-tempered scale is formed by selecting any note as a key and applying the twelfth root of 2 as a ratio to find the frequencies of the other notes of the scale.

Musical instruments are classified according to the nature of the vibrating bodies that produce their tones. The three classes are the stringed instruments, the wind instruments, and the percussion instruments. The frequency of a vibrating string is inversely proportional to the length of the string. It is directly proportional to the square root of the tension and inversely proportional to the square root of the mass per unit length.

Will sound travel faster on a cold or a warm day? Why?

Which produces the longer sound wave, a high-pitched voice or a low-pitched voice? Why?

Do high tones and low tones travel with the same speed?

If a playing band is in the front of a long marching column of soldiers, what excuse based on physics could be given for the soldiers at the rear of the column to be out of step with the soldiers at the front of the column?

Why are echoes not heard in small rooms?

EXPLORING THE WORLD OF SOUND

Often a tone of a certain pitch from your piano or radio will cause a wire supporting a picture on the wall to vibrate. Explain this?

How may beats be used to tune two musical instruments?

Why can you often identify your friend's voice over the telephone?

How can you identify a speaker's or singer's voice over the radio?

How does a violinist produce so many different pitches while playing? How does he change the pitch of a string while tuning it?

PROBLEMS

1. How fast will sound travel in air when the temperature is 30°C .?

2. If the time required to hear an echo is 3 seconds and the temperature of the air is 20°C ., how far away is the reflecting surface?

3. If you sing middle C, which has a vibration of 256 per second when the temperature is 15°C ., what is the wave length of the note?

4. If a vibrating fork which has a frequency of 512 is held over the open end of a closed tube, what will be the velocity of sound if the first and second resonance length are 6 in. and 18 in., respectively?

5. How many beats per second will two tuning forks give with frequencies of 512 and 516 respectively?

6. If the first note of a major scale is 256, what are the frequencies of the other notes?

7. What is the frequency of each note of the even-tempered scale if the keynote has a frequency of 240?

INVESTIGATIONS

1. Check the time required to hear thunder after the flash of lightning is seen. Explain your results.

2. Visit a broadcasting station and see how the walls are made to produce good acoustics.

3. Examine a pipe organ and explain how different tones, qualities, and intensities are produced.

4. Check the three tones heard when the station identifications on your radio are given and find out what tones they are and their ratio of frequencies.

5. Notice the pitch of an automobile horn, first, as it approaches you and, second, as it leaves you, and account for the difference.

6. Identify the different instruments heard in an orchestra as its music reaches you over the radio. Explain why you are able to do this.



Sailing vessels such as these often lost their way for want of an accurate guide. The magnetic compass now enables men to guide huge ocean liners directly to any port in the world.

A First Assistant to Electricity — Magnetism

MAGNETISM AND SCIENTIFIC PROGRESS

Man's knowledge of magnetism has been intimately related to his progress throughout the past thousand years. Before the compass with its magnetized needle came into use, sailors seldom ventured far from shore. They feared losing themselves in the trackless ocean which was inhabited by great monsters ready to devour any unlucky sailor who took his ship too far.

**UNIT
SEVEN**

FIRST ASSISTANT TO ELECTRICITY—MAGNETISM

After the compass was invented, sailors began to venture farther from land. They found new lands but no monsters beyond the horizon. Thus the magnetic compass removed the superstitions of the sea, enlarged the horizon of the peoples of the earth, and led to the discovery of a new world.

In more recent times a thorough knowledge of magnetism has been required in the designing of such important instruments as the telegraph and the telephone. Electric motors and generators, transformers and induction coils, all require controlled magnetic fields. If you were asked to design a machine with no moving parts, with an efficiency higher than 95 per cent, and with the capability of transmitting many hundreds of horsepower, you might think it a difficult task. The modern transformer does this and more, utilizing a magnetic field as the conveyer of the energy.

Although we still do not know just what magnetism is, we do know a great deal about what magnetism can do, and we have put this knowledge to work in a most effective way. This unit presents the basic facts concerning magnets and magnetic fields.

AREAS OF STUDY

- 1. What are the characteristics of a magnet?*
- 2. Why is iron attracted by a magnet?*
- 3. What is a magnetic field?*
- 4. What is the nature of magnetism?*
- 5. What is known concerning the earth's magnetism?*

AREA ONE

What Are the Characteristics of a Magnet?

Let us take two small bars of steel of the same size and weight. One attracts tacks and small pieces of iron, and the other does not. If we suspend the bars so that they can turn, one invariably

CHARACTERISTICS OF A MAGNET

points north and south and the other one does not. The difference in the bars arises from the fact that the first bar is a magnet and the other is not. The first possesses a force, known as magnetism, that the other completely lacks. This force is of special importance because of its role in the operation of electrical devices. Consequently, to understand the operation of these devices, we must first learn something about magnetism.

Two kinds of magnets—natural and artificial. There are two kinds of magnets, natural and artificial. The natural magnet was discovered in ancient times when it was observed that magnetite, a form of iron ore, attracted small pieces of iron. The word *magnetite* probably comes from *Magnesia*, ancient name of a district in Asia Minor where the ore is plentiful. Magnetite is also known as lodestone, *lode* meaning “direction,” because when pieces of this material are suspended they invariably point north and south. We learn from the writings of the ancient Greeks that they discovered how to make artificial magnets by stroking pieces of iron with natural magnets. These artificial magnets possessed the property of assuming a north-and-south line as do natural magnets and soon took the place of natural magnets.

Today manufacturers make artificial magnets in two ways: first, by stroking bars of steel in one direction with a magnet; and second, by passing electric currents around the bars. The latter method is by far the more widely used, especially in magnets made for electrical purposes. Most magnets are made in the shape of a horseshoe or

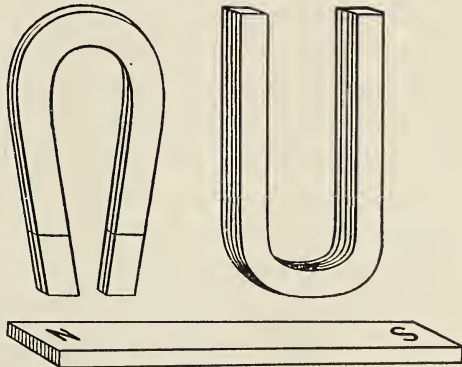


Fig. 178. Three different shapes for a simple magnet.

of the letter **U**, as shown in Figure 178. Other magnets are made in the form of a bar as shown in the lower part of the drawing.

FIRST ASSISTANT TO ELECTRICITY—MAGNETISM

Interesting laws of magnets. The magnetic force of a magnet, regardless of the shape of the magnet, is concentrated at the ends. We can readily see that this is true by dipping a magnet into iron filings. The filings cling to either end but fail to attach them-

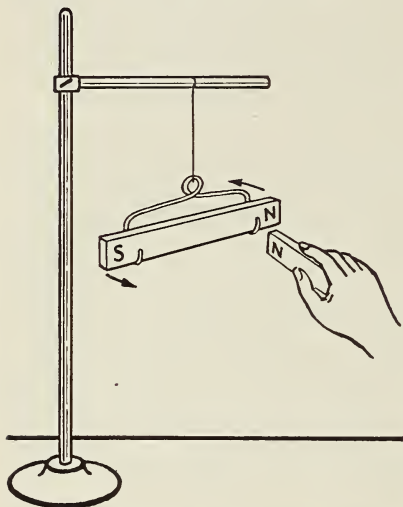


Fig. 179. Apparatus for demonstrating the behavior of a bar magnet suspended in air.

selves to any other part. The ends of a magnet, or the parts where the magnetic force is concentrated, are known as the poles.

If we suspend a bar magnet so that it is free to turn in any direction, as shown in Figure 179, we find that it invariably assumes a north-and-south position with the same end pointing north and the other end pointing south. Regardless of how we turn the bar—even if we turn it end for end—it always returns to the same position, with the same end pointing north. Because of this tendency of a mag-

net to assume a position in a north-and-south line, the end that points to the north is commonly known as the north pole and the end that points to the south as the south pole. The quality possessed by magnets of having opposite poles, one north-seeking and the other south-seeking, each exerting a force opposite to that of the other, is called polarity.

Now let us perform another experiment with the suspended magnet by bringing close to the north pole of the magnet the north pole of another magnet, as shown in Figure 179. We find that the north pole of the suspended magnet turns away from the north pole of the magnet held in the hand, showing that the two north poles tend to avoid, or to repel, each other. If we repeat the experiment by bringing the south pole of a magnet close to the south pole of the suspended magnet, we notice the same repelling effect. Now let us reverse the experiment by bringing

CHARACTERISTICS OF A MAGNET

the south pole of a magnet close to the north pole of the suspended magnet. In this case the north pole of the suspended magnet turns toward the south pole of the magnet held in the hand, showing that these two poles tend to come together, or to attract each other. If we bring the north pole of a magnet close to the south pole of the suspended magnet, we note the same evidence of attraction. On the basis of such experiments, scientists have developed the following law, known as the law of magnets: *Like poles of magnets repel and unlike poles attract.*

Scientists have carefully studied the forces of repulsion and attraction between the poles of magnets and have evolved a mathematical formula for their relationship. Thus the forces are said to be directly proportional to the strength of the poles and inversely proportional to the square of the distance between the poles. Often the forces are expressed in dynes, a dyne being a unit of force. A pole is said to be of unit strength if it repels a similar pole one centimeter away with a force of one dyne.

The magnetic compass. Shortly after the ancients discovered the lodestone and learned how to make artificial magnets, they began to use magnetized bars for determining directions. Near the end of the thirteenth century, about two hundred years before Columbus discovered America, the device known as the compass came into use. This device exerted great influence upon the world because up to that time sailors had no accurate means of telling directions once they lost sight of land. With the aid of the compass, however, they began to travel farther from shore and finally made many notable discoveries, including the discovery of the continent upon which we live.

The ordinary compass consists of a small bar magnet that is free to turn upon a point, as shown in Figure 180. The magnet is inclosed in a case somewhat like the case of a watch, and on the front is a dial laid out in directions

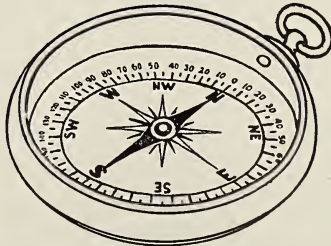


Fig. 180. Ordinary magnetic compass.

FIRST ASSISTANT TO ELECTRICITY—MAGNETISM

and degrees corresponding to the degrees in a circle. To use the compass, a person merely aligns point *N* on the dial with the north end of the needle, which always points in a northerly direction. Then, having determined north, he can determine other directions by noting the data on the dial.

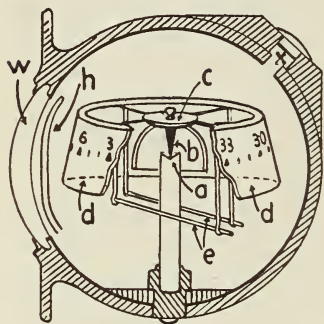


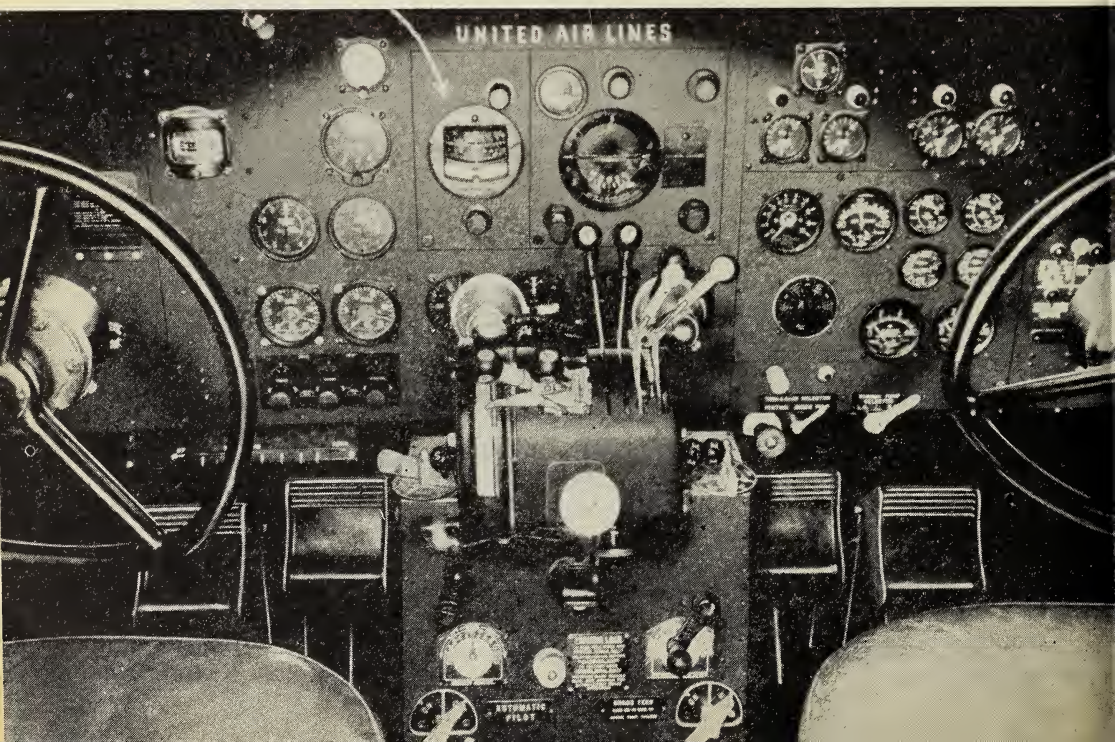
Fig. 181. Side view of magnetic compass used for navigation purposes.

One of the most interesting forms of the magnetic compass is the compass used in the navigation of airplanes. Figure 181 shows a cross-sectional view of an airplane compass. The parts consist of pivot cup *a*, rotating pivot *b*, and disk *c*, which is supported by pivot *b*. Attached to the disk is a cone-shaped card *d*, upon

which is a scale graduated in degrees from 0° to 360° , with large numerals that indicate units of ten degrees, as 3 for 30° , 6 for 60° , and so on. Suspended from the card are two bar magnets *e*, one on either side of the pivot. At the front is a window or opening *w* through which the pilot reads the scale. On the glass of the

View of part of the instrument board of a modern air liner. The location of the magnetic compass is indicated in the photograph by a white arrow.

United Air Lines Photo



CHARACTERISTICS OF A MAGNET

window directly in the center is a vertical white line *h* known as the lubber line. The card bearing the scale always rides on the pivot in a north-and-south direction because it turns with the

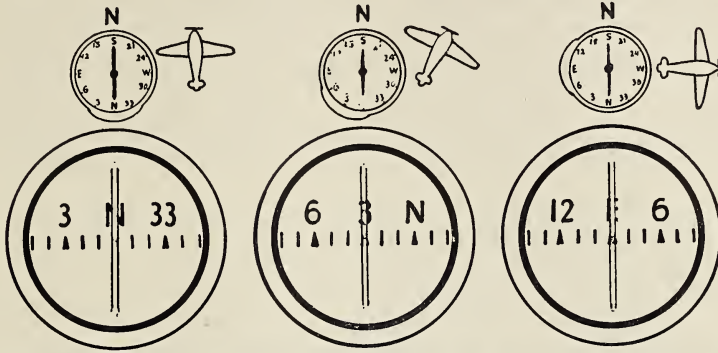


Fig. 182. The whole compass box including the lubber line turns east or west with the plane, while the magnet and the scale remain stationary in a north-and-south position.

magnets, which maintain a north-and-south direction. Therefore, regardless of the direction in which the airplane travels, the scale always points north and south. The lubber line, on the other hand, which is a line painted on the glass window of the compass or a bar attached rigidly to the central pivot support, turns with the airplane. When an airplane is headed 30° east of north, the lubber line is directly in front of the 30° point on the scale. When an airplane is headed directly east, 90° east of north, the lubber line is in front of the *E* on the scale (Fig. 182). From such compass readings the pilot knows exactly in what direction he is flying.

The compass of an airplane is exceedingly sensitive and hence is affected by the near-by metal parts of the airplane and other distorting factors caused by the electric current. These disturbing elements cause the scale beneath the lubber line to turn, so that the lubber line does not indicate the true direction in which the airplane travels. Thus the compass installed in every new airplane is carefully tested before the airplane is put into use. The readings of the compass are compared with the readings of a true compass and the deviations are noted. The other magnets, known as compensating magnets, are installed to help counteract the deviations.

FIRST ASSISTANT TO ELECTRICITY—MAGNETISM

To find the compass course to be followed, however, still other factors must be considered, as we shall learn later in the unit.

What are magnetic materials? Any materials are said to be magnetic when they are attracted by magnets. The most important magnetic materials are iron and steel, and others of lesser importance are cobalt and nickel. Certain alloys also strongly magnetic are those known as Heusler alloys, which consist of 65 per cent copper, 27 per cent manganese, and 8 per cent aluminum. All materials attracted by magnets are commonly known as paramagnetic. Certain materials, such as bismuth and antimony, instead of being attracted by magnets are repelled by them. These materials are known as diamagnetic. Certain other materials such as glass are wholly unaffected by magnets, being neither attracted nor repelled by them. All such materials are known as nonmagnetic.

ANSWER THESE QUESTIONS

1. What is the difference between natural magnets and artificial magnets? How are artificial magnets made? In what shapes are magnets made?
2. What position does a bar magnet assume when free to move, as when suspended from a cord?
3. What happens when the north pole of a magnet is brought close to the north pole of a suspended magnet? What happens when the south pole of a magnet is brought close to the north pole of a suspended magnet?
4. What law governs the action of magnets when like and unlike poles are brought near each other?
5. What is a compass? How does an ordinary compass work? How has the compass assisted in the sailing of ships?
6. How are errors in compass readings caused by the near-by metal parts and electric current of the airplane partly overcome?
7. What are magnetic materials? How are materials commonly classified with reference to the effect of magnets upon them?
8. What are paramagnetic materials?
9. What happens when a magnet is brought near a bit of antimony? What is the name given to such materials?

AREA TWO

Why Is Iron Attracted by a Magnet?

We may have wondered a good deal about the strange powers that are given to pieces of iron and steel when magnets are brought near them. Scientists, too, have wondered about the phenomenon and have conducted many interesting experiments to arrive at a reasonable explanation. We shall now consider some of the experiments and the explanation that they have provided.

What is meant by magnetic induction? If we attract an unmagnetized tack with a bar magnet, as shown at the left in Figure 183, and put the point of the tack in iron filings, the filings cling to the point, showing that the tack has become magnetized. If we remove the tack from the magnet, the filings fall off the point of the tack. If we attract the tack again, we may attach other tacks as shown at the right in Figure 183 until the weight of the tacks overcomes the force of attraction. All the tacks in the chain become magnetized because of the attraction of the magnet. Whenever we bring a magnet into contact with a piece of soft iron or in close proximity to it, magnetic force is produced temporarily in the iron. The magnetic force that is produced in this way in a piece of iron or other metal, with or without contact, is called induced magnetism.

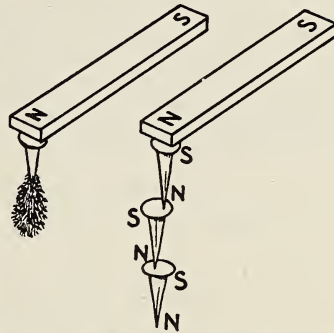


Fig. 183. Illustrations of the effects produced by magnetic induction.

If we test with a compass the free end of a tack attached to a magnet we find the pole at that end to be the same as the pole at the end of the magnet to which the tack is attached. The free end of the magnet and the attached end of the tack also have the same pole. In the same way if a pole of a magnet is brought near a piece of soft iron, the pole at the nearer end of the piece of iron will be opposite to that of the magnet. For example, if the south

pole of a magnet is brought near one end of the piece of soft iron, that end of the iron will have an induced north pole, and the other end an induced south pole. This arrangement of poles in a magnetized material is the general law of magnetic induction.

Iron filings attached to the end of a magnet, as in Figure 183, assume a bushlike appearance. That is because the free ends of the filings have the same poles, and since as we have learned like poles repel each other, the free ends spread out from each other.

Retentivity and permeability. The foregoing experiments show that soft iron is very easily magnetized. Had we used a piece of hard steel such as a needle instead of the tack, very few filings would have clung to the needle because steel is magnetized less strongly than soft iron by the presence of a magnet. However, unlike the soft iron, steel when magnetized retains its magnetism much more readily. This property of resisting magnetization or demagnetization is called retentivity. The harder the steel, the greater its retentivity. For this reason permanent magnets are made of hard steel.

The property of being easily magnetized as shown by the soft iron is called permeability. High permeability is generally accompanied by weak retentivity, as in soft iron, which is easily magnetized and easily demagnetized. For this reason the cores of electromagnets are generally made of soft iron or soft steel. When especially weak fields are desired, an alloy of iron and nickel called permalloy is used, the permeability or weakness of retentivity of which is thirty times as great as that of soft iron.

Magnetic screening. Magnetic fields pass through nonmagnetic substances but are stopped, at least in part, by magnetic substances. If a sheet of paper, glass, rubber, copper, or any other nonmagnetic material, for instance, is placed between a magnet and a compass, the compass is unaffected by the material. If a thick sheet of iron or steel is placed between a magnet and a compass, however, the steel serves as a screen and the effect of the magnet is greatly decreased. A space inclosed by a thick wall of



Keystone View Co.

The steel structure of modern buildings affects the magnetic needle to such an extent that true north and south cannot be discovered with a compass inside the building.

iron is nearly completely screened off from external magnetic effects. The steel girders in a building may partially screen off the earth's field from the interior of a building so that a compass inside does not point in the same direction as one outside.

ANSWER THESE QUESTIONS

1. Explain how induced magnetism differs from permanent magnetism.
2. Why is the force of attraction of a magnet for a nail greater than the force of repulsion?
3. Why are permanent magnets made of hard steel?
4. Why are electromagnets made of soft iron?
5. Can a magnetic field be screened off from a body by being painted or by being inclosed in glass or paper? Explain.

AREA THREE

What Is a Magnetic Field?

The simple experiments provided in this area reveal the fact that the influence of a magnet prevails only through a limited space surrounding the magnet. The extent of this space varies with the size and strength of the magnet.

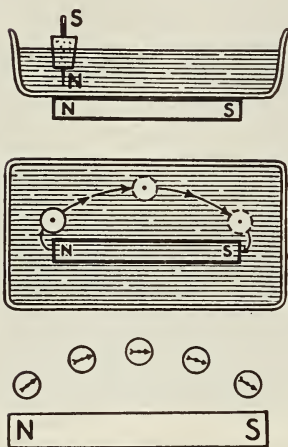


Fig. 184. Illustrations of an experiment with lines of force.

Magnetic lines of force. Suppose a glass vessel containing about two inches of water is placed upon a bar magnet, as shown in the upper drawing in Figure 184. A strongly magnetized needle is then thrust through a cork and floated in the water with the south pole up and the north pole down. When the needle is placed over the north pole of the bar magnet, it floats from north to south, following a curved line as shown in the second drawing in Figure 184. This curved line represents what is known as a magnetic line of force. A line of force may be defined as the path that an in-

dependent north pole takes in going from the north pole to the south pole of a magnet. We may also trace a line of force by arranging a series of compasses so that the needles form a line as shown in the lower drawing in Figure 184 or by moving a compass from north to south in the line indicated by the needle of the compass. It may be said, then, that the direction of a line of force at any one given point in the line is the direction indicated by the needle of a compass at that point.

Magnetic lines of force are believed to be closed circuits, as in Figure 185.

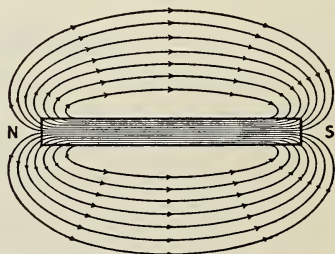


Fig. 185. Behavior of magnetic lines of force of an ordinary bar magnet.

THE MAGNETIC FIELD

Coming out of the magnet at the north pole, the magnetic lines of force pass through the air to the south pole, where they enter and return through the magnet to the north pole.

Magnetic field composed of magnetic lines of force.

The space around a magnet in which its force may be detected is called the field of force of the magnet. We may observe the manner in which the lines of force arrange themselves in a magnetic field of force by sifting iron filings upon a piece of paper above a bar magnet. As we drop the filings, they arrange themselves in accordance with the lines of force passing from the north to the south pole of the magnet, as shown

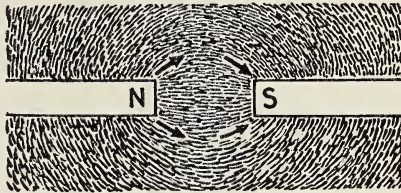
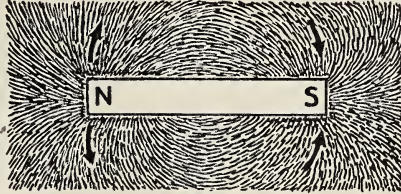


Fig. 186. Drawings showing arrangement of magnetic fields around the two poles.

at the top in Figure 186. If we drop iron filings on paper over the north and south poles of two separate magnets placed about one inch apart, we find that the iron filings again arrange themselves in accordance with the lines of force, as shown at the bottom in Figure 186. In the latter situation, however, the magnetic field of force is stronger than in the former, and consequently magnets are made in the shape of the letter **U**.

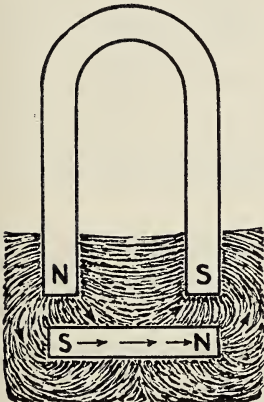
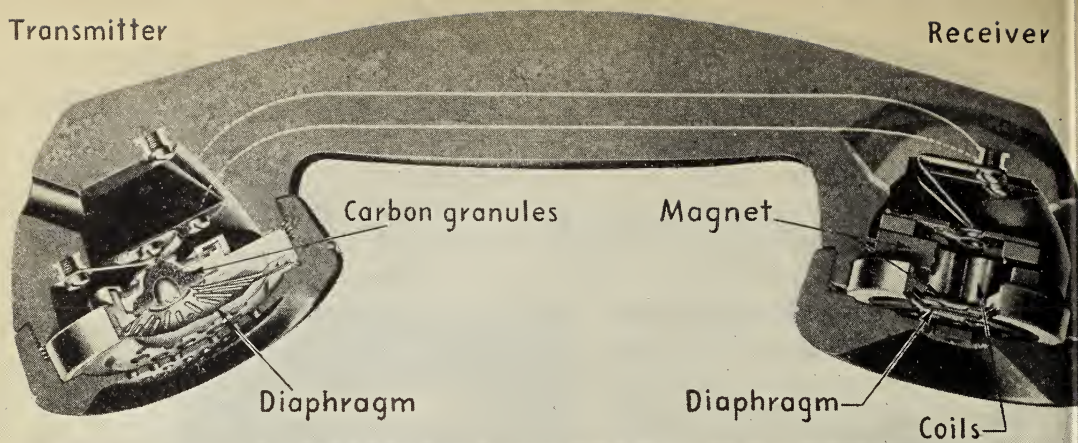


Fig. 187. Lines of force in relation to magnetic fields.

If we continue the experiment by sifting iron filings upon paper placed over a **U**-shaped or a horseshoe magnet with a bar of soft iron placed about one-half inch from the poles, we find that the iron filings concentrate closely about the poles of the magnet as shown in Figure 187. In other words, the lines of force appear to close



Courtesy A. T. & T. Co.

A permanent magnet is an essential part of many devices. In telephone receivers, airplane magnetos, speedometers, electric bells, meters, and many other instruments, permanent magnets are indispensable for successful operation of the device.

together rather than spread through a larger area. This condition shows that the soft iron bar is a much better conductor of magnetic force than is air, and may therefore be said to have greater permeability than air. Because of this fact a soft iron bar, known as a keeper, is frequently placed in contact with the poles of a U-shaped magnet to help preserve its magnetism.

A magnetic field of unit strength is defined as a field in which a unit pole experiences a force of one dyne. A field of unit strength is represented as having one line of force per square centimeter. We may represent such a force graphically, as illustrated in Figure 188, by drawing one line per square centimeter through a surface placed at right angles to the lines of force between magnets.

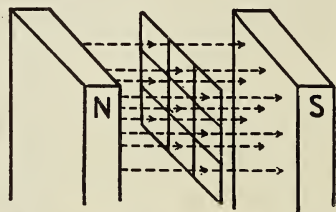


Fig. 188. Lines of force passing through units of a magnetic field.

ANSWER THESE QUESTIONS

1. Explain how the direction of the lines of force in a magnetic field is determined.
2. If a line of force is followed from the north pole of a magnet, where will it eventually lead?
3. Why are some magnets bent into a U-shaped form?
4. Explain how the strength of a magnetic field is determined.

AREA FOUR

What Is the Nature of Magnetism?

Scientists have discovered that certain conditions have a definite influence on the strength and properties of magnets. A reasonable theory explaining the phenomenon of magnetic force has developed from these discoveries. In this area we shall discover what the theory is and why users of the scientific method are willing to accept it as valid.

Magnets affected by jars and by heat. There are many indications that a sudden jar affects the magnetism of an object. For example, if we pound a magnetized needle, we greatly lessen the magnetism of the needle. On the other hand, if we place an unmagnetized needle between the poles of a **U**-shaped or a horseshoe magnet and pound the needle, it becomes magnetized. If we stroke a small test tube of iron filings with one of the poles of a magnet, the filings take on the properties of a magnet. They arrange themselves into lines of force with reference to the north and south poles. If we shake the iron filings after they have been magnetized, they lose this magnetism completely.

In a similar way, heat affects the magnetism of an object. If we heat a magnetized needle until it is red-hot and allow it to cool, we find that it loses its magnetism. If we heat an unmagnetized needle and allow it to cool between the poles of a **U**-shaped or a horseshoe magnet, it becomes magnetized. Likewise heating and cooling a magnetized test tube of iron filings destroys the magnetism.

The theory of magnetism. The foregoing experiments seem to indicate that when the molecules of an object are affected, the magnetism of the object is affected. Let us now consider another experiment that seems to indicate that magnetism is associated with the molecules. If we magnetize a small bar of steel by stroking it from end to end with one of the poles of a bar magnet, and then cut the bar in two, we find that each part acts as a

FIRST ASSISTANT TO ELECTRICITY—MAGNETISM

magnet with north and south poles as shown in Figure 189. If we cut one of these parts in two, we find that each part likewise acts as a magnet with north and south poles. Regardless of how many times we cut the bar in two, each smaller part acts as a magnet. We may assume that, if we were to continue the cutting

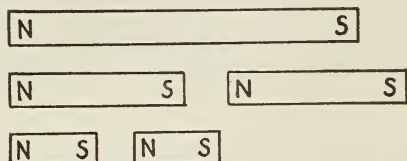


Fig. 189. Each of the segments cut from a magnetized bar acts as a separate magnet with north and south poles.

into smaller and smaller pieces, we should finally reach a point where the pieces would be only molecules, each molecule serving as a magnet.

On the basis of the foregoing experiment and others of a similar nature, scientists advance the theory that each molecule of a

substance acts as a magnet, attracting unlike poles and repelling like poles. In an unmagnetized bar of iron the molecules are arranged in a haphazard manner or in such a manner that the opposite poles of the molecules tend to neutralize one another, as shown in the upper diagram of Figure 190. In the case of a magnetized bar, on the other hand, the molecules align themselves or combine their strength at both ends of the bar to form the north pole at one end and the south pole at the other, as seen in the lower diagram of Figure 190. The molecules between those at the two ends of the bar

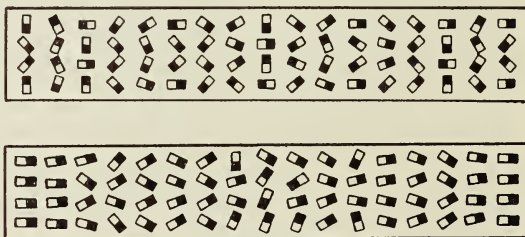


Fig. 190. Effect of magnetism on arrangement of molecules.

remain in a haphazard arrangement, their opposite poles tending to neutralize each other as in the case of the unmagnetized bar.

One proof of the theory is the fact, already explained, that the magnetism of objects is affected by jars and by heat. On the one hand, the jarring and the heating tend to destroy the magnetism; and, on the other hand, the jarring and the heating of an

THE EARTH'S MAGNETISM

unmagnetized bar placed between the poles of a magnet help the molecules of the bar to realign themselves and produce magnetism.

One of the easiest materials to magnetize is soft iron, because its particles readily swing into alignment. Steel is more difficult to magnetize than soft iron, but the heating or the jarring of a steel object, as just explained, causes the molecules to realign themselves readily. Once magnetized, a steel bar retains its magnetism longer than a magnetized iron bar, because the molecules are more firmly aligned.

More evidence for the correctness of the theory is the fact that a piece of iron or steel cannot be magnetized beyond a certain limit. When this limit is reached, no increase in the strength of the magnet is produced by the increase of the magnetizing force. The magnet is then said to be saturated. The limit may be explained by the fact that all the molecular magnets have been arranged in parallel lines as shown in Figure 191.



Fig. 191. Arrangement of molecules in a saturated magnet.

ANSWER THESE QUESTIONS

1. How can a person make four magnets out of one?
2. In terms of the theory of magnetism, what is the process of magnetizing an iron bar?
3. Why is there a limit to the strength of a magnet?
4. Why are the poles of a magnet near its ends?
5. Explain why heating or jarring tends to weaken a magnet.

AREA FIVE

What Is Known concerning the Earth's Magnetism?

Doubtless we are already aware of the fact that the earth is a vast magnet. We know that flyers use the knowledge of the earth's magnetism in charting courses and flying directly to desired

destinations. We also know that Columbus must have known about terrestrial magnetism in order to carry out his voyages of discovery. In this area we shall learn many new and useful facts concerning terrestrial magnetism. In some instances we may correct misunderstandings as well.

What is meant by terrestrial magnetism? One of the most interesting facts about magnetism is the fact that the earth itself is a magnet, with poles where the lines of force concentrate. One of these poles, commonly known as the north magnetic pole, is situated at $73^{\circ} 31'$ north latitude and $95^{\circ} 48'$ west longitude. This pole was first discovered in 1831 by the explorer Sir James Ross, and relocated in 1905 by the explorer Roald Amundsen. According to the findings of these men the pole is slowly moving west, and it is now about 2° farther west than when first located by Ross. The south magnetic pole is situated at $72^{\circ} 25'$ south latitude and $155^{\circ} 18'$ east longitude. The location of this pole was determined in 1909 by Sir Ernest Henry Shackleton.

As we have already learned, a bar magnet that is free to turn and the needle of a compass always come to rest in a north-and-south line. One of the poles of the bar or needle, referred to as the north pole, always points north, and the other pole, referred to as the south pole, always points south. As a matter of fact, however, since like poles repel each other and unlike poles attract each other, we may think of the north pole of a bar magnet or the needle of a compass as a north-seeking pole and of the corresponding south pole as a south-seeking pole.

The angle of declination. Since the earth's magnetic poles are not situated at the same points as the geographic poles, the needle of a compass, except in a few places on the earth's surface, points slightly away from the true north. The angle between a meridian, which is a true north-and-south line, and the direction of the needle in a compass is called the angle of declination. The U. S. Coast and Geodetic Survey prepares maps that show lines, known as isogonic lines, passing through points having the same

THE EARTH'S MAGNETISM

declination (Fig. 192). The line connecting points with zero declination and separating points with declination east or west is referred to as the agonic line. Part of this line passes through

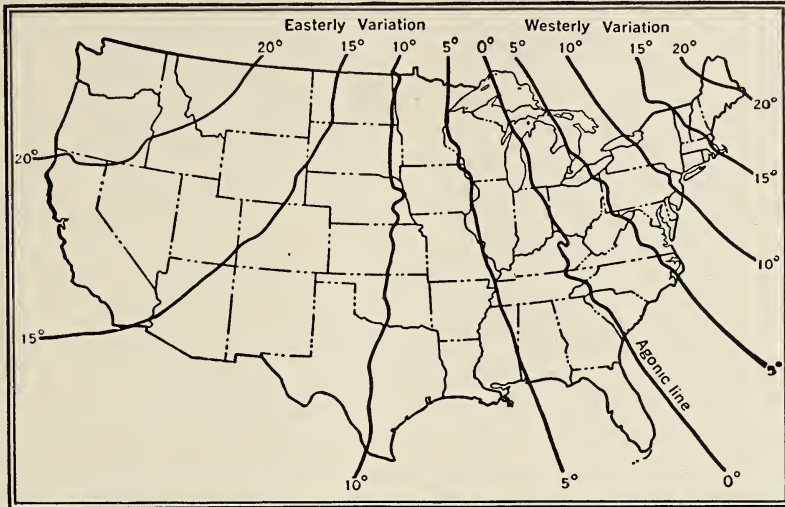


Fig. 192. Map showing lines of equal magnetic variation in the United States at 5° intervals. These lines of equal magnetic variation are known as isogonic lines.

South Carolina, eastern Tennessee, Kentucky, western Ohio, northern Indiana, and Michigan. Places east of this line have declination to the west and places west of the line have declination to the east. If we trace the isogonic lines on a map of the world, we find that in the Northern Hemisphere they converge to a point known to be the north magnetic pole and that in the Southern Hemisphere they converge to a point known to be the south magnetic pole. Irregularities seen in the lines on the map are caused by the presence in various regions of great deposits of iron and other metals that influence the force of magnetism and cause deviations in the needle.

How pilots of airplanes are concerned with declinations. In the early days of aviation, airplane pilots guided their flights largely by landmarks such as mountains, rivers, cities, and towns. Today, however, because much flying is done at night and in stormy

weather when visibility is poor, pilots depend partly upon a method of using the compass and a map. This method is known as dead reckoning. The pilot draws a line through *A* and *B*, the

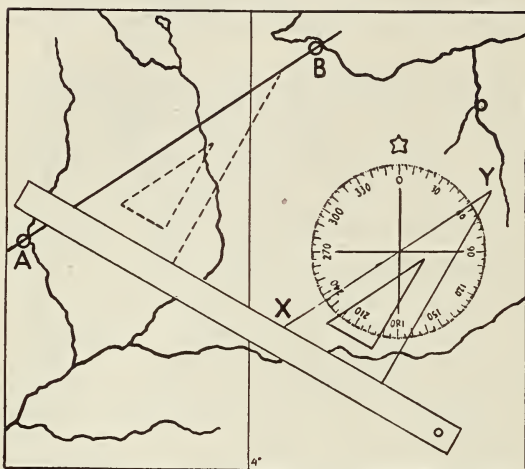


Fig. 193. Method for plotting a true course on a map.

points of departure and destination, as shown in Figure 193. He then draws a line *XY* through the center of the nearest compass rose parallel to the first line *AB*. This gives him his true course.

Flying the true course, however, usually does not lead the pilot to his destination. He must take into consideration the amount of declination, shown

on the isogonic map. This information enables a pilot to follow a course known as the magnetic course, which takes into account the angle of declination. Suppose, for instance, that a pilot wishes to fly from one city to another and that the true course follows an angle of 30° east of north. When he looks at the isogonic lines on the map, however, he finds that the declination where he is flying is 3° west. He therefore adds 3° to 30° and flies 33° east of north by his compass rather than 30° east of north.

Finding the compass course. Earlier we noted that certain errors in the compass readings on an airplane are caused by the near-by metal parts and the electric current. These errors, which in the field of aviation are known as deviation, are partially overcome by the use of compensating magnets. The remaining errors must be taken into account by the aviator in charting his course. The deviation varies with different airplanes and with different directions of flying. Therefore each new airplane is carefully tested

THE EARTH'S MAGNETISM

for compass errors, and a special deviation chart is prepared. This chart is attached to the airplane, so that the errors may be conveniently read. After finding his magnetic course, as just explained, the pilot corrects the magnetic course by taking into account the number of degrees west or east indicated by the deviation chart. If there is little or no wind, or if the wind blows in the direction of flight, he may follow the compass course. If there is a cross wind, however, he must head into the wind and make a further correction, known as wind correction.

The angle of inclination or dip.

If two unmagnetized knitting needles are thrust through a cork at right angles to each other and the ends of one needle are placed upon supports, the second needle may be balanced in a longi-

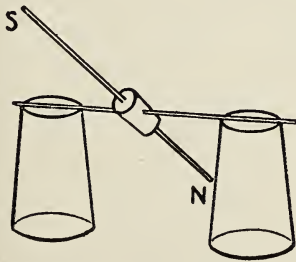


Fig. 195. Experiment for showing the behavior of a magnetized needle.

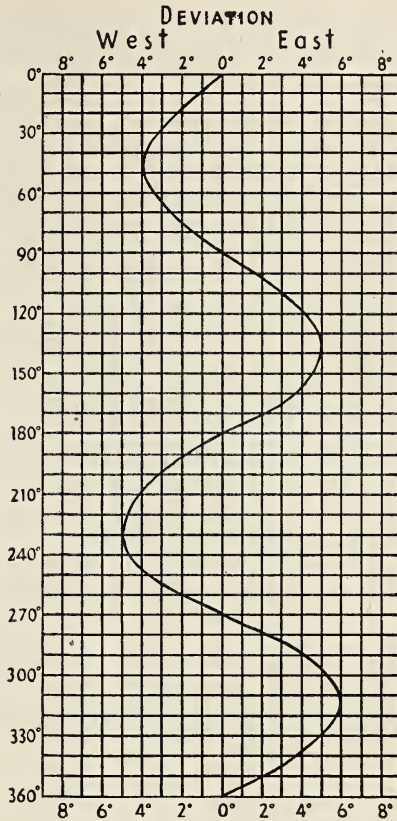


Fig. 194. Chart showing deviations of the compass for various directions of flight in a certain type of airplane.

tudinal plane regardless of how it is turned with reference to the earth's lines of force. If the second needle is replaced by a magnetized needle, the north pole of the magnetized needle dips downward, as shown in Figure 195, because the needle aligns with the earth's lines of force. The dip of the needle shows that the earth's lines of force are not horizontal in our

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latitude. Only at points midway between the magnetic poles is the magnetic needle horizontal. The angle between the horizontal and the line of the needle is called the angle of inclination or dip.

The inclination varies as we go from north to south; in the Northern Hemisphere it becomes less until a place is found where the angle of inclination is zero. The imaginary line connecting points of zero inclination, known as the magnetic equator, is near the geographic equator. North of the magnetic equator the north-seeking pole of a magnet dips, and south of the magnetic equator the south-seeking pole dips. Moving northward, the angle of dip in the United States varies from 55° to 78° , increasing in Canada to 90° at the north magnetic pole. Figure 196 shows an ordinary dipping needle.

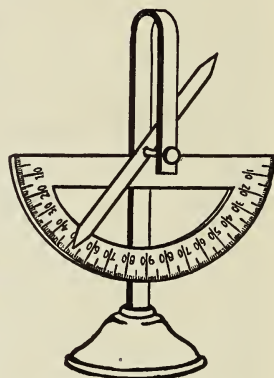


Fig. 196. Diagram of an ordinary dipping needle.

The earth's inductive action. If we hold an unmagnetized iron rod parallel to the earth's lines of force, as shown by a compass and dipping needle, and then pound the rod with a mallet, we find

Producing a magnet by induction from the earth's magnetic field. When the iron rod is hammered, the molecules in the rod are arranged in line with the earth's magnetic field.



that the bar becomes magnetized with the north pole at the bottom. This experiment is like the experiment in which we pounded an unmagnetized needle held between the poles of a magnet, except that in this instance we depend upon the magnetic lines of force of the earth for the inductive action. If we reverse the direction of the rod and pound it again, we discover by testing with a compass needle that the poles have also been reversed. From these facts perhaps we can

SUMMARY

explain why the bottom of an iron flagpole or an iron fence will repel the north pole of a magnetic needle. What is the explanation?

ANSWER THESE QUESTIONS

1. Why is the N pole of a magnet called a north-seeking pole?
2. In what direction would a compass point in Alaska? in Greenland? at the north geographic pole?
3. How can we explain the probable behavior of a compass needle at the south magnetic pole of the earth?
4. What is an agonic line, and how is it used?
5. Of what value is an isogonic chart?
6. How can a magnet be made by use of an iron bar and a hammer?
7. How did the earliest flyers discover their way from one place to another? Mention conditions under which the modern method of charting a course is safer and more satisfactory.
8. What is the difference between the true course, the magnetic course, and the compass course in navigation?
9. What is the angle of inclination or dip?

SUMMARY

Magnets are of two kinds, natural and artificial. A piece of magnetite, or lodestone, is a natural magnet because in its natural state it possesses polarity. Artificial magnets can be made by stroking pieces of steel or soft iron with a natural magnet, or by passing electric currents around pieces of steel or soft iron. When a magnet is freely suspended, it assumes a north-and-south line. This property of a magnet renders it very desirable for use in magnetic compasses. The ends of a magnet are called poles. One end is called a north pole and the other a south pole. Like poles repel and unlike poles attract.

Magnetic induction is the process by which magnetism is induced in a substance by the presence of a permanent magnet, with or without contact. The property of a substance that resists magnetization or demagnetization is called retentivity. The property of a substance that permits easy magnetization or demagnetization of the molecules is called permeability.

FIRST ASSISTANT TO ELECTRICITY—MAGNETISM

Magnetic lines of force are defined as the path that an independent north pole would take if it went from the north to the south pole. A magnetic field is composed of lines of force. The unit of strength of a magnetic field is defined as a field in which a unit pole experiences a force of one dyne.

The theory of magnetism assumes that each molecule in a magnetic substance is a magnet. The molecules at one end of a magnet combine to form a north pole, and those at the other end combine to form a south pole.

The airplane pilot must understand the effect on his compass of magnetic declination and the magnetic deviation caused by metal parts of his plane. These influences have been worked out and charted for his guidance.

The earth is a large magnet, having north and south magnetic poles. Because the earth is a magnet, it has a field of force. The angle of declination is the angle between a meridian that is true north and the direction in which the needle of a compass points.

How could a knife blade be magnetized with a permanent magnet?

If a magnet were placed in a pile of iron filings, upon what parts of the magnet would the filings be most numerous?

Why do not magnetic compasses always point true north?

How can a compass be shielded from a magnetic field?

How does a steel flagpole become a magnet?

Which end of a vertical steel flagpole is the south pole in the Northern Hemisphere?

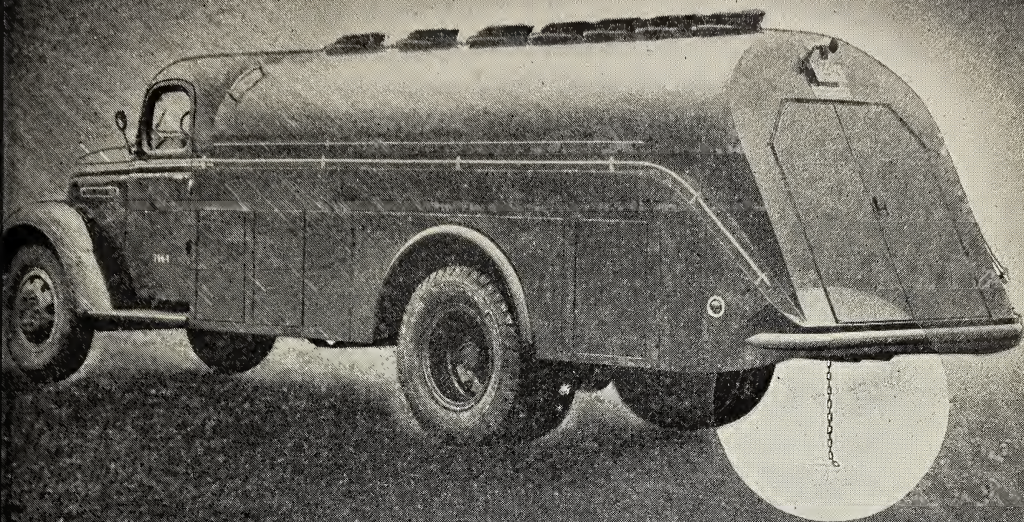
INVESTIGATIONS

1. Examine the flagpole at your school and determine whether the bottom of the flagpole is a north or a south magnetic pole.

2. Hold a soft iron rod in your hand at about 60° angle with the horizontal. Strike the rod sharply with a hammer several times and with a compass examine the polarity of the rod.

3. Secure two permalloy magnets and examine their magnetic fields.

4. If possible, examine and explain the workings of compasses used on battleships, freight or passenger ships, airplanes, and yachts.



The piece of chain that dangles to the ground from every gasoline truck represents an application of physics that has prevented the loss of many lives and many gallons of gasoline.

UNIT EIGHT

Mischief-Makers among Electrons

STATIC ELECTRICITY

Do you know why many gasoline trucks have chains dangling to the ground, as illustrated in the picture above? A college student discovered the need for such a chain while he was driving a gasoline truck during his vacation. One day as he alighted from the truck he happened to touch a metal part of the vehicle and received a slight shock. This occurrence led him to the conclu-

MISCHIEF-MAKERS AMONG ELECTRONS

sion that the metal parts of a truck carry charges of electricity. Having studied physics in both high school and college, he reasoned that the electrical charge is caused by friction between the gasoline and the metal walls of the tank. As the truck is driven, the gasoline splashes against these walls and thus causes the metal parts of the truck to become charged with electricity. The student considered the situation with some alarm, for he realized that sometime, in driving, the charge might become so great that sparks of electricity would ignite the fumes of the gasoline. Accordingly he conceived the plan of attaching to the truck a chain long enough to drag upon the ground. The purpose of the chain is to carry the electricity, as it forms, to the earth, thus neutralizing the charge on the metal parts of the tank.

Workmen in a large manufacturing concern were annoyed by electrical shocks when they came near a certain steam pipe. After making a survey, the electrician found that this pipe was not in contact with any "live" wire in the establishment, and reasoned that the electrical charge on the pipe must be produced by the friction of the steam passing through it. To free the pipe from the charge he connected one end of an insulated copper wire to the pipe and the other to an iron stake driven into the ground. This connection carried into the ground the electrical charges accumulating on the steam pipe, and the workmen had no reason for further complaint.

The electrical charges in both the metal parts of the truck and the steam pipe were charges of static electricity, often called frictional electricity because it develops when two unlike objects are rubbed together. Static electricity is stationary or motionless as distinguished from current electricity, which is the kind generated for ordinary use. The latter type is called current electricity because the electricity is in motion. Both types of electricity, according to modern theory, are caused by the activity of countless minute particles known as electrons, which help to make up the structure of atoms. In this unit we shall consider static electricity and from this study learn many principles which we may apply later in our study of current electricity.

AREAS OF STUDY

1. *What is static electricity?*
2. *How is the electrical condition of a body detected?*
3. *How is electricity conducted through solids?*
4. *What is lightning?*
5. *How are electrical quantities measured?*

AREA ONE

What Is Static Electricity?

Perhaps we have noticed that if we rub a fountain pen with a piece of cloth the pen attracts bits of paper when it is brought near them. The bits of paper cling to the pen much as small pieces of iron cling to a magnet. Sometimes when we walk over a rug we feel a shock when we touch a metallic object such as a doorknob. The shock occurs because the friction between our shoes and the rug has caused our body to become charged with electricity. The electricity in both these instances is static electricity, or electricity at rest, rather than current electricity, or electricity in motion. Let us now observe what static electricity is like and how it behaves.

History. Electrical properties were known to the Greeks many centuries ago. In 600 B.C. Thales discovered that amber, when rubbed with woolen material, had this force of attraction for light bodies. But that was all that the Greeks found out about electricity. There is no record of their having tried to electrify anything but amber. To us who live in this age of scientific experimentation the fact seems strange that twenty-two hundred years should elapse before the discovery was made that this same effect could be produced by means of rubbing many other

MISCHIEF-MAKERS AMONG ELECTRONS

materials together, such as hard rubber and fur, sealing wax and flannel, glass and silk. It was not until 1600 A.D. that Sir William Gilbert, the physician of Queen Elizabeth, announced

that this effect, which he called *electrification* from the Greek *elektron*, meaning "amber," could be produced in other substances besides amber.

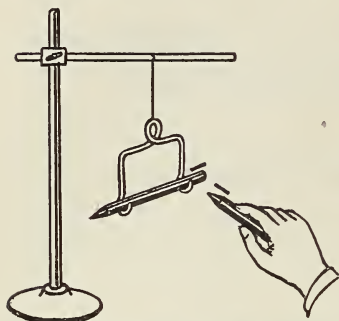
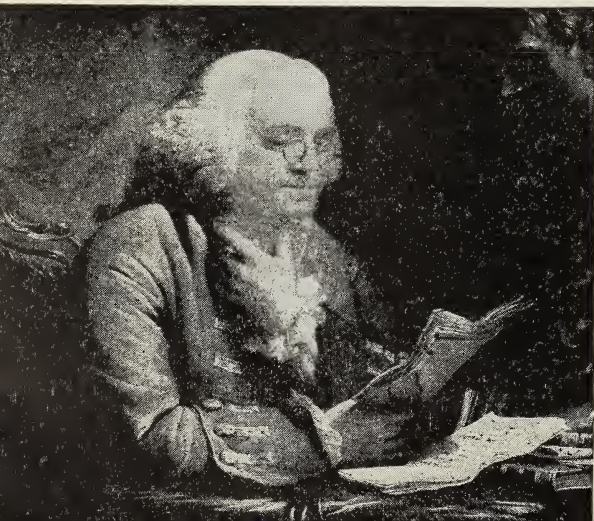


Fig. 197. Experiment for demonstrating that like charges repel each other.

Electrification of two kinds. To understand how charged bodies react toward one another, let us charge two ebonite rods by rubbing them with fur. When we have finished charging the rods, we suspend one by a silk thread so that it may turn freely and

then bring the second rod near the suspended one as shown in Figure 197. We find that the suspended rod turns away from the rod in our hand. If we now rub a glass rod with silk and bring it up to the suspended rod, we find that the suspended rod moves toward our hand. Since we used the same process in charging the ebonite rods, we may conclude that their charges are alike and repel each other. On the other hand, we may conclude that the charges on the glass rod and the ebonite rod are unlike and attract each other. From these and other similar experiments which we might perform with rods of other materials, we conclude that electrification is of two kinds, or that there are two kinds of electrical charges. Bodies that are electrified with the same kind



Benjamin Franklin (1706-1790)

Franklin, the fifteenth child of a poor colonial American family, learned the printing trade at an early age and soon owned his own printing office. He played a conspicuous part in public affairs and achieved fame as a writer, philosopher, and humanitarian. In addition to these capacities he possessed inventive ability. His contribution to science was his discovery that lightning is electricity.

of charge repel each other, whereas those that are electrified with the opposite kind of charge attract each other. *These forces of attraction and repulsion are found to be directly proportional to the product of the amount of charge and inversely proportional to the square of the distance between them.* Note the similarity of this force to the force of gravitation.

Positive and negative electricity. From Benjamin Franklin's experiments with the electrical action of various substances come the modern terms *positive charge* and *negative charge*. Franklin thought electricity was a fluid and that bodies were positively charged when they had an excess of the normal quantity of this fluid, and negatively charged when they were lacking the proper quantity. He arbitrarily gave the name *positive* to the bodies that react in a manner similar to the glass rod when rubbed with silk and *negative* to the bodies that react in a manner similar to the ebonite rod when rubbed with fur.

Modern scientists have discovered many new facts concerning electricity that show that Franklin's theory was incorrect, although it served to explain the known facts in his day. Franklin believed the process of charging a body to be a flow of positive electricity, but now we know that the charging process is a flow of negative electricity. The modern theory is more nearly correct than Franklin's, because it not only explains everything that his theory explains, but also a great many other facts that his theory will not explain. A glass rod rubbed with silk, therefore, is said to be positively charged, not because it has gained positive electricity, but because it has lost negative electricity.

Electricity and atoms. The modern theory of electricity had its origin in the closing years of the last century with the discovery of electrons, X-rays, and radioactivity. These new fields of physics made possible the direct study of the structure of atoms, as indicated in Unit One of this book. It is the electrons, the negatively charged particles, that are so loosely bound to the rest of the atom that they may be transferred from one body to

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another. The protons with their positive charges constitute, in large measure, the massive part of the atom. Protons can be taken from atoms, but only by forces that are enormously great as compared with the forces required to take one or more electrons away from the atom.

ANSWER THESE QUESTIONS

1. When was electrical charging by friction discovered?
2. What contributions did Gilbert make to the knowledge of electricity?
3. How can it be shown that two bodies with like charges repel each other?
4. How can it be shown that bodies having unlike charges attract each other?
5. What was Franklin's theory of the nature of electricity?
6. What are the most important differences between Franklin's theory and the present theory of the nature of electricity?

AREA TWO

How Is the Electrical Condition of a Body Detected?

Few boys and girls have reached high-school age who have not had startling experiences with electrically charged objects. But they know only that some strange force exists in such objects. Scientists, however, need to be able to detect an electrical condition with accuracy. They need to know, not only that an electrical condition exists in a body, but also whether the electrical charge is positive or negative in character. This area will describe and explain what methods and devices are used by scientists to achieve this purpose.

Detection of the electrical condition of a body. To detect the electrical condition of a body, an electroscope is used. A simple electroscope may be made of pith balls suspended by silk threads.

DETECTING AN ELECTRICAL CONDITION

If an uncharged body is brought up to the pith balls, there is no reaction. If an ebonite rod that has been rubbed with fur is brought near the pith balls, they are attracted. The ebonite rod has been given an excess of electrons and is negatively charged. If the pith balls are allowed to touch the ebonite rod, they are repelled and repel each other as shown in Figure 198. This reaction is due to the fact that the balls have received electrons from the rod and have become negatively charged. If we rub a piece of paper on a coat sleeve and bring it near the charged pith balls, we can determine the nature of the charge on the paper by seeing whether the pith balls are attracted or repelled. If they are attracted, the charge on the paper is unlike that on the balls; if they are repelled, the unknown charge is like the known charge on the balls.

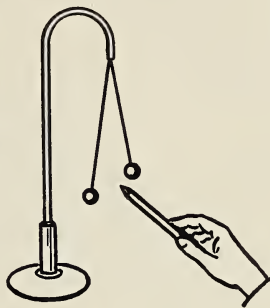


Fig. 198. Experimenting with a simple electroscope.

A more sensitive electroscope than the pith balls consists of a metal rod with a ball on one end and two very thin strips of gold or aluminum foil on the other. Such an electroscope is usually mounted in a case to protect the fragile foil from air currents. An electroscope of this type is shown in Figure 199.

The use of the electroscope. Let us charge an ebonite rod by rubbing it with fur. Then let us bring the rod close to but not touching the knob of the electroscope. The leaves diverge, as shown in Figure 199, but they fall together again when the rod is removed. Now let us bring a glass rod that has been rubbed with silk close to the electroscope. The leaves diverge as before. The ebonite rod is negatively charged and the glass rod is positively charged, yet the leaves of the electroscope diverge just as readily for one as for the other. We may conclude, therefore, that an

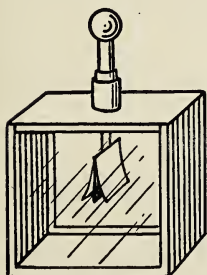


Fig. 199. Electroscope

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uncharged electroscope does not indicate the nature of the charge. One must first put a known charge on the electroscope. If a charged ebonite rod is touched with a proof plane made of a penny fastened to a stick of sealing wax, and the ball of the electroscope is then touched with the same proof plane, the leaves on the electroscope diverge and remain apart. The leaves diverge because the proof plane passes electrons to the electroscope. This process is called charging by conduction, and the charge is positive or negative in accordance with the charge carried by the charging body.

The electroscope may be charged just as well if a glass rod carrying a positive charge is touched with the proof plane. However, in this case the glass rod takes electrons from the proof plane, the proof plane takes electrons from the electroscope, and the electroscope is charged positively. We have seen also that if a body with an unknown charge is brought near an electroscope on which there is a known charge and the leaves diverge, the body carries the same charge as the electroscope. If the leaves fall together, the unknown charge is opposite to that on the electroscope.

ANSWER THESE QUESTIONS

1. What is an electroscope?
2. What is meant by charging by conduction?
3. Why do the pith balls repel each other after being touched by a charged ebonite rod?
4. How can the electroscope be used to help demonstrate the fact that bodies with unlike charges attract each other?

AREA THREE

How Is Electricity Conducted through Solids?

Handles of electric switches are frequently made of rubber. The telephone receiver is made of composition rubber. A man wearing rubber boots would not be in so much danger from fallen



Ewing Galloway

When changing the carbon in an electric street lamp, the electrician protects himself from severe shock by wearing rubber gloves.

charged wires as a person wearing other footgear would be. This means that rubber is a poor conductor of electricity. Occupants of automobiles are seldom struck by lightning. Why certain materials are said to be good conductors while other materials are poor conductors of electricity is explained in this area.

Nonconductors. It was early observed that glass, sealing wax, and amber can be electrified by friction. Let us take a copper rod and rub it with flannel. When we bring it to the electroscope, we see that it has not been charged. We shall try again, but this time we shall put small pieces of sealing wax or glass around the part grasped by the hand so that the hand does not touch the metal. Again, we rub the copper with the flannel. We make the test and see that the rod is charged. We find that metals cannot be

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charged if touched by the hand, while glass, sealing wax, and ebonite may be. When we put electrons on the ebonite rod by rubbing with fur, the electrons stay on the atoms where they were put. The electrons placed on the metal rod do not remain where placed, but move along the rod into the hand and thence through the body to the earth as fast as they are placed on the rod by the fur.

Conductors. Let us try another experiment. We connect an insulated metal ball by a copper wire to the electroscope as shown in Figure 200. If the ball is touched

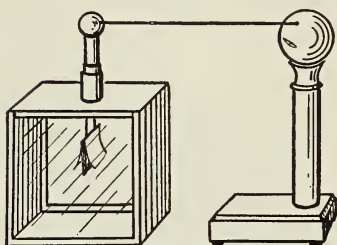


Fig. 200. Electroscope used in experiment for determining the conductivity of electrical charges.

with a negatively charged ebonite rod, the leaves spread apart, showing that the electrons placed on the ball have produced a charge on the electroscope through the wire. If we remove the copper wire and replace it by a silk thread, no divergence of the leaves is seen when electrons are placed on the ball, showing that there is no movement of electrons along the

thread. We may conclude that electrons will pass readily along a metal wire but not along a silk thread. The metal is a conductor and the silk is a nonconductor. The same experiment may be made with a positively charged body, a glass rod rubbed with silk. However, in that case the electrons will travel in the opposite direction along the wire and not at all along the silk thread.

In metals the electrons are held in the atoms by a slight attraction between the electrons and nucleus and hence move freely from atom to atom. In nonmetals, such as glass, rubber, and silk, the electrons are held in the atoms by a strong attraction between the electrons and nucleus and hence do not move freely from atom to atom. Such substances as glass, rubber, and silk are very poor conductors of electricity, whereas metals are good conductors. Solutions of acids, bases, and salts in water are also good conductors. Glass, porcelain, sulfur, mica, shellac, wood,

HOW ELECTRICITY IS CONDUCTED

vaseline, turpentine, paraffin, and oils are called insulators. There are no perfect insulators, since there are no materials that do not conduct electricity to some extent.

Speedy current, slow electrons. The metal rod cannot be electrified when held in the hand because electrons escape from it to the hand as fast as electrons are put on it. This does not mean that the same electrons leave the rod as are put on it. When electrons are added at one end of the rod, they exert a repelling force on the electrons already on the rod. These immediately move a short distance down the rod, and in so doing exert a repelling force on those farther along. The force is transmitted with very great speed to the other end of the rod. The effect is somewhat analogous to the transmission of pressure by fluids. An increase in pressure at one point causes a nearly instantaneous increase throughout the body of the fluid. The speed of the electric current is very great; yet the motion of the individual electrons forming the current is very slow, perhaps only several inches per second. This slow motion, however, when started among the electrons at one end of a long conductor, is communicated, from electron to electron throughout the length of the conductor at almost the same instant.

Electrostatic induction. Let us bring a negatively charged rod near the end of an insulated, oblong metal body provided with pith balls *A*, *B*, and *C* as shown in Figure 201. *A* and *C* at the ends diverge, while *B* does not, showing that the ends are charged and that the middle is not charged. The charged rod will attract *A* but repel

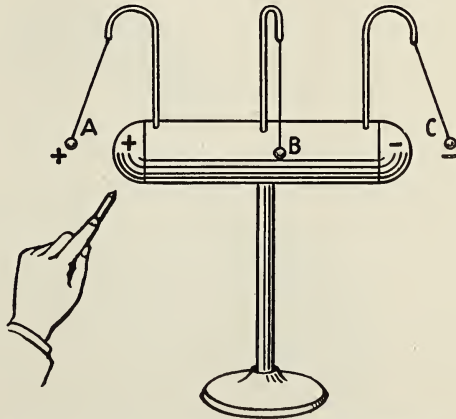


Fig. 201. Apparatus used to show the repelling and attracting effects of like and unlike charges.

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C, showing that *A* has an unlike charge and *C* a like charge. From this experiment we may conclude that, when a conductor is brought near a charged body, the end nearest the body becomes charged with the opposite kind of electricity and the farther end with the same kind of electricity.

An electroscope charged by induction. Suppose we bring a negatively charged ebonite rod near the knob of a gold-leaf electroscope as shown in the photograph. The leaves diverge because the electrons on the ebonite rod repel the electrons on the electroscope and cause an excess of electrons to appear on the leaves that charges them negatively. Since they are charged alike, they repel each other. As electrons have been driven from the knob, it is positively charged. Now let us take the ebonite rod away and we notice that the leaves go together. As soon as the rod is removed, the electrons driven by it from the knob to the leaves return and the leaves become neutral again. If the rod is brought close to the knob of the electroscope again, the leaves diverge as before.

The girl is observing the reactions of a sensitive electroscope as she charges it by holding an ebonite rod that has been rubbed with fur close to the metal knob.



HOW ELECTRICITY IS CONDUCTED

While the rod is still there, if the finger is placed on the knob as shown in Figure 202, the leaves fall together. The electrons that were on the leaves have gone into the hand and through the body

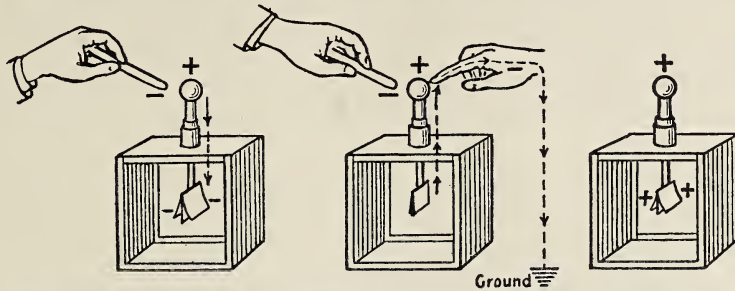


Fig. 202. Experiment showing effects of charges produced in an electroscope.

into the ground. If the finger is removed while the rod is still there and after that the rod, the leaves diverge again, showing that they are charged. If the charged ebonite rod is brought near, the leaves go together. If a glass rod charged by being rubbed with silk is brought near the electroscope, the leaves are seen to go farther apart. This experiment shows that the charge on the electroscope is positive. The electroscope is charged because the hand took the electrons from it, leaving it without the proper number to balance the positive charges. This process is known as induction. The charge produced by induction is always opposite to the charge that induced it.

Distribution of electrical charges on a conductor. Let us place a metal vessel on an insulated stand or some insulating material such as glass, sulfur, or sealing wax, and strongly charge it by induction with an ebonite rod. Now if we touch the inside surface with a proof plane as shown in Figure 203 and bring the proof plane near an electroscope, the leaves do not diverge, showing that the proof plane received no charge when it touched the inside of the vessel. Next let us touch the outside of the

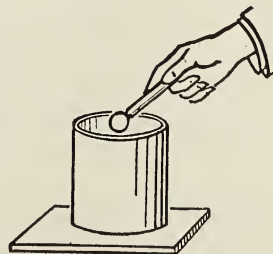


Fig. 203. Experiment with charges in a conductor.

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vessel with the proof plane. The electroscope shows that the proof plane is now charged, indicating that the charge placed on the vessel has all passed to the outside surface. This experiment shows that an electrical charge on a body is found on the outside surface. This is explained by the fact that like charges repel. The little charges making up the total charge repel one another and thus get as far apart as possible; therefore, they go to the outside.

Greatest density of a charge. If an elongated conductor such as is shown in Figure 201 is charged and the charges on the ends and the middle are tested by being touched with a proof plane, the pronounced divergence of the pith balls at the ends shows that the

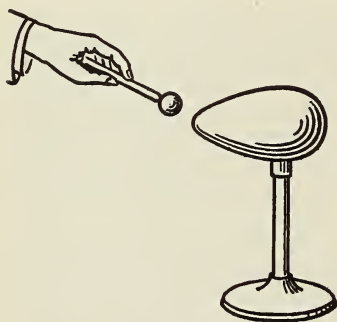


Fig. 204. Apparatus for locating the greatest density of a charge.

charge is most dense at the ends. By density of a charge is meant the amount of electricity per unit of area. If a conductor is egg-shaped similar to the one in Figure 204, we can show by using a proof plane that the charge is densest at the pointed end. The electrical density is greatest where the degree of curvature is greatest. If a conductor ends in a point, the density may become so great at the point that the charge escapes into the air. The intensity of the charge at the point electrifies the air, causing some of the air molecules to lose electrons. These electrons go to other molecules and charge them negatively. The air in this state is said to be ionized, which means that some of the air molecules are charged positively and some negatively. The air molecules with a charge opposite that on the point of the conductor are attracted to it and the conductor is discharged. Air molecules with a like charge are repelled.

Sparks from points. The discharging effect of points may be shown by a needle, held in the hand, brought near the knob of a charged electroscope. The leaves of the electroscope fall together. If the

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electroscope has a negative charge, the needle becomes charged positively by induction. As has been explained previously, the air is ionized and the molecules of the opposite charge are drawn to the knob of the electroscope and thus discharge it.

Let us place an electric whirl on a pin point on an insulated stand and connect it by a conductor to a knob of an electrical machine as shown in Figure 205. If the machine is started, the electric whirl will begin to turn away from its points. Explain this reaction.

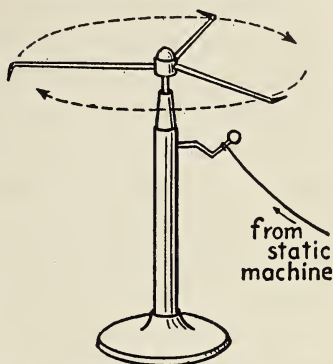


Fig. 205. Electric whirl shown backing away from its points.

ANSWER THESE QUESTIONS

1. Name several substances that are good conductors.
2. Name several substances that are good insulators.
3. How does the addition of an electrical charge to a conductor affect the other charges on the conductor?
4. Why is it easier to charge an ebonite rod by friction than it is to charge a copper rod by friction?

AREA FOUR

What Is Lightning?

Primitive man feared the "Thunder God," who inflicted unexpected and undeserved punishment on mankind. In early times men made sacrificial offerings to appease the anger of this capricious god. Much later, men who were capable of critical thinking tried to use the scientific method in explaining the action of lightning. In more recent times, as we shall see, some of the first experimenters, like Franklin, did not arrive at a full understanding of underlying principles. But their work laid the foundation for the scientific facts that are explained in this area.

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Lightning, an electrical discharge. In 1752 Benjamin Franklin, believing that lightning is the discharge of electricity from cloud to cloud or from a cloud to the earth, performed an experiment by flying a kite during a thunderstorm. This kite had a pointed rod at the top and attached to the lower end of the kite string was a key from which sparks appeared. Such an experiment is very dangerous and should not be tried by students. A Russian scientist was killed in attempting to perform the experiment. Following his experiment, Franklin invented the lightning rod, and his instructions for installing the equipment are still considered fairly accurate. He believed that the rod should be made of very heavy wire, with one end driven several feet into the ground and the top end well sharpened.

The present theory of the lightning rod is that it discharges silently by inductive action the static charge in a cloud and thus prevents a disruptive discharge. Also, if there is a flash of lightning it helps to conduct the current safely along the wiring to the ground. To work properly, lightning rods must project some feet above the highest part of a building and must be properly grounded and insulated. The rods must be made of a good conducting material.

Danger from lightning. A lightning flash is an intense discharge of static electricity, sometimes several miles long. The path is probably less than an inch in diameter, though it appears much larger owing to the extremely bright light emitted. The injury done to animals that are very near a flash, but not actually struck, is due to the powerful electrical shock. Any object actually struck is damaged by the intense heat developed. The great majority of lightning flashes are from one part of a cloud to another part of the same cloud. They do, however, strike the earth frequently. It is therefore advisable to take certain precautions to avoid being struck during storms. One precaution is to avoid using isolated trees or buildings for shelter, since these are good targets for lightning. It is best to keep away from high places and take shelter in a hollow or lie flat on the ground away from trees

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and fences. Wire fences may conduct the discharge some distance from the place where it strikes. The shores of bodies of water should be avoided, since electrical discharges seem to seek the edges of conducting surfaces. People or animals in groups also seem to be in more danger than one person or animal. In case of injury by lightning artificial respiration should be given.

ANSWER THESE QUESTIONS

1. How should lightning rods be installed to be most effective?
2. Why are sharp points effective in neutralizing the charge on an electroscope?
3. What would be a safe place in a thunderstorm?
4. Name various objects that a person should stay away from in a thunderstorm.
5. What method should be used to revive a person struck by lightning?

Besides the single zigzag flash and the parallel flashes like unraveled rope shown here, flash lightning is often forked or in tree shape with endless branches.



How Are Electrical Quantities Measured?

In modern life electricity has become the efficient servant of man. The full story of man's understanding and control of this strange force is one of the most interesting and dramatic in the whole history of human progress. Few of the present-day scientific uses of electricity would be possible if we had not learned how to measure the quantity of this seemingly magic power necessary for various purposes. This area will explain how scientists have learned to measure the quantity of electricity just as accurately as the dairyman can measure the milk in his bottles.

Elementary charge. The charge of one electron is called the elementary charge. It is the smallest quantity of electricity. Its measurement by Professor R. A. Millikan in 1913 is considered one of the most important achievements in the whole history of physics. The procedure is far too intricate and involved to be explained in this text. Scientists have repeatedly demonstrated the accuracy of Millikan's work. Through its use a great contribution to the exact measurement of electrical quantities has been made.

Electrostatic unit. The attraction and repulsion of electrical charges is used as a basis for the electrostatic unit. The electrostatic unit of a charge is that quantity of electricity which, when placed one centimeter away from an exactly equal and similar charge, will repel it with a force of one dyne. A body carrying an electrostatic unit of negative charge has an excess of 2,095,000,000 electrons on it, and a body carrying an electrostatic unit of positive charge has lost that many electrons.

Coulomb. A larger and more practical unit of the quantity of electricity is called the coulomb, and is named after the French scientist Charles Augustin Coulomb. There is a coulomb of electricity on a body when it is charged with three billion electrostatic unit charges. If we place six billion billions of electrons on

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an insulated conductor, we have added to the body about one coulomb of electricity. In the 25-watt lamp used in home lighting, about one-fifth of a coulomb of electricity is used per second, which means that about one and one-quarter billion billions of electrons are moving through it per second. The coulomb measures the quantity of electricity just as a quart is used to measure milk. It measures the quantity of electrical charge, whether that charge is standing still on a conductor, when it is known as static electricity, or whether it is in motion on a conductor, when it is known as current electricity.

The ampere. In speaking of the flow of water through a pipe, we say that it is flowing at the rate of a certain number of gallons per second. But in measuring electricity, we do not say a certain number of coulombs per second because we have the word *ampere*. The ampere is the unit by which we measure the rate of flow of electrons through a conductor. It means that a coulomb of electricity is moving past a given point per second, or 6.285 billion billion electrons are moving past the point per second. This means just the same thing as, when speaking of a parade, we say that a certain number of people are passing the reviewing stand every hour. The word ampere is more familiar to us because it is used to measure the electricity in motion that lights our homes and runs our electric motors.

Potential and capacitance. Let us suppose that we have two vessels of the same cross-sectional area and the same height connected by a pipe with a stopcock as shown in Figure 206. If water is poured into vessel A, with the stopcock closed, until it is full, and into B until the water in B is half as high above N as the height of the water in A is above M, we know that the pressure at M is twice as great as at N. When the stopcock is opened, this difference in level in the two vessels causes the

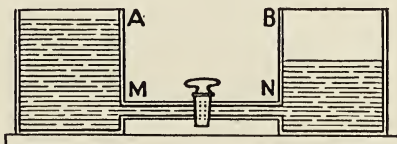


Fig. 206. Apparatus for showing the effect of potential upon the flow of water.

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water to flow from *A* to *B* until the level in both is the same, and then the flow stops. The rate at which the water flows from vessel *A* to vessel *B* depends upon the size of the pipe and the opening in the stopcock.

Potential difference and flow. The same type of experiment may be conducted to show differences in the potential of electricity. Suppose that we fasten with wax two silk threads of the same length to two metal vessels of the same size and at the loose end

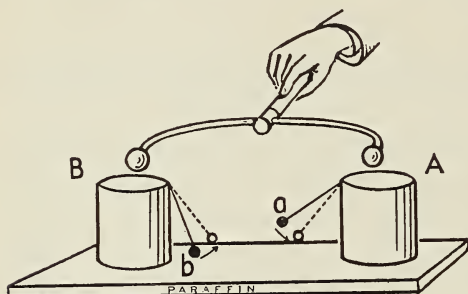


Fig. 207. Apparatus for showing the effect of potential upon the flow of electricity.

of each thread attach a pith ball. Then let us place the two metal vessels about 10 inches apart on some insulating material, such as paraffin, as shown in Figure 207. With an ebonite rod let us place electrons on *A* until the pith ball *a* stands out, and charge *B* with the same kind of charge until its pith ball *b* stands out about one-half as far as the one on *A*. About twice as many electrons have been placed on *A* as on *B*, and, as the vessels are the same size, the pressure of the electrons, or the electrical potential, of *A* is twice as great as that of *B*.

Now suppose that we connect the two vessels with a conductor such as the discharging rod shown in Figure 207. The pith ball on *A* is seen to fall and that on *B* to rise until they are the same distance from their respective conductors. This change in position of the balls shows that electrons have moved from *A* to *B* until the same quantity is found in each and they are at the same level or potential. Just as water tends to flow from a higher level, or hydrostatic pressure, to a lower level, so electricity flows from points of higher electrical pressure to points of lower electrical pressure, or potential. Just as in Figure 206 the water will flow only as long as there is a difference in level, so the electrons will flow along the conductor from *A* to *B* in Figure 207 as long as the

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potential of electricity in the two bodies is different. When water is standing still, the surface level is the same at all points; if electricity at all points of a conductor or connected conductors is at the same potential, the electrical charge is stationary, or in a static condition.

Continuous currents. If in Figure 206 water had been poured into *A* and allowed to escape from *B* by an exit pipe at the same rate, the different levels would have been maintained and a continuous flow of the water would have resulted. To get a continuous flow of electricity from *A* to *B* in apparatus similar to that shown in Figure 207, electrons must be supplied to *A* and removed from *B* at the same rate. Apparatus similar to that shown in Figure 207 may be used to show potential difference. Let us connect *A* to the knob of an electrical machine and *B* with the ground. The pith balls show that *A* is kept at a higher potential than *B*, and a continuous flow of electrons is the result. The important fact to remember is that the difference of potential causes the electrons to flow, thus making a current of electricity. Difference of potential is denoted by the letters P.D.

Measurement of potential difference. The unit by which potential difference is measured is the volt, and the instrument used to measure P.D. is called the voltmeter. Since the earth is a conductor, the potential of the earth is the same everywhere. If its potential is considered zero, it makes a convenient standard of reference in measuring potentials. To show the potential difference between a body and the earth, a gold-leaf electroscope with a metal case is used. If the metal case is grounded by connecting it with the earth, it has the potential of the earth, or zero. When the body to be tested is connected with the knob of the electroscope, the divergence of the leaves indicates the potential difference between the charged body and the earth.

Voltmeters. We can construct a simple electrostatic voltmeter by mounting a light aluminum vane in a metal ring in the same

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position as the gold leaf in an electroscope, as in Figure 208. The outer ring is connected with the earth at point *A*. The rod *B* is insulated from the ring at *C*, and the light aluminum vane is pivoted at its middle point. The body whose potential is to be measured is connected to *B*, and the divergence of the vane is measured on a scale that is calibrated in volts. This is a very satisfactory voltmeter for measuring large voltages. The voltmeters used in the study of electricity are the ones generally used by electricians and are made on a very different principle. The explanation of how electricians measure P.D. is deferred until later.

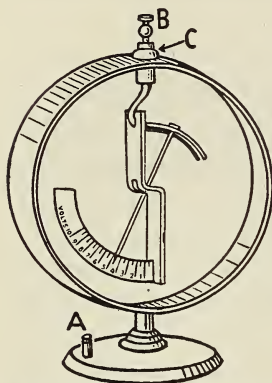


Fig. 208. Diagram of a simple electrostatic voltmeter.

We are so accustomed to measuring quantities such as time, weight, and distance that the units and instruments used to measure them are familiar to us. Electrical energy is now being so nearly universally used that we know about electrical units and electrical measuring instruments. The ammeter is as common today as the yardstick because every automobile has an ammeter on its instrument panel to indicate the rate the battery is being charged or discharged. Homes that use electrical energy have meters to indicate the amount consumed. We shall be more intelligent consumers of electrical energy if we understand the units and the instruments used in measuring this energy.

Capacitance. Let us suppose that we have two vessels of different cross-sectional areas as shown in Figure 209. *A* has four times the cross-sectional area of *B*. Suppose that water is poured into *A* until it is filled to the height *C* and into *B* until the water is at the same level in both vessels. Because the vessels are connected, there is no flow, for

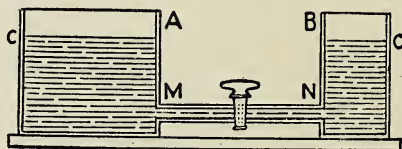


Fig. 209. Vessels of different capacities arranged for experiment with flow of water.

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the water is at the same level in both and the pressure at M is equal to the pressure at N . Four times as much water was poured into A as into B , but both have the same level and the same hydrostatic pressure. The capacity of A is thus four times the capacity of B .

Capacitance, dimensions, and charge. Two conductors of different sizes with A four times as large as B , are set up on an insulator. Pith balls a and b are arranged as shown in Figure 210. B is charged negatively with a proof plane that has been touched to a charged ebonite rod until the pith ball b stands out about an inch. A is charged in the same way until its pith ball a is at the same distance, showing that both conductors have the same potential. Let us count the number of times the proof plane is applied to each vessel to get

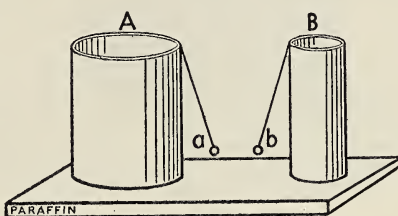


Fig. 210. Apparatus for demonstrating the relation of capacitance and potential.

both of them to the same potential. We shall find that A must be touched four times as often as B . This experiment proves that four times as many electrons are required to bring A up to the same potential as B . The capacitance of A is four times the capacitance of B . (In recent years the term *capacitance* is being used instead of *capacity* in electrical measurement.) We may conclude that the larger the conductor, the greater the quantity of electricity that must be put into it to bring it to a required potential. The electrical capacitance of any device is measured by the quantity of electricity that it holds at unit potential.

For a given conductor the potential is directly proportional to the quantity of electricity present. The capacitance of the conductor is equal to the quantity divided by its potential. Algebraically $C = \frac{Q}{P.D.}$. The unit of capacitance is the farad. A farad is the capacitance of a conductor into which a coulomb of electricity may be put with a potential difference of one volt. Because



The student is investigating the factors that control the capacity of a condenser. The measuring instrument she is observing is an electroscope.

this is a very large capacitance, the unit most generally used is the microfarad. A microfarad is one-millionth of a farad.

Condensers. In 1745, in the city of Leyden, P. van Musschenbroek, a renowned physicist at the University, was trying to electrify some water in a glass jar by means of a wire from an electrical machine. An assistant held the jar in his hand; after a while he wanted to remove the wire and took hold of it with his other hand. He was much surprised when he received a severe shock through his hand to his arm and breast. Both of the scientists were at a loss for an explanation when they tried to account for this effect. They knew that a large quantity of electricity was suddenly discharged when they touched the inner and outer surfaces of the jar at the same time. But why was this quantity so large and where did it come from? Let us perform some experiments in order to discover what the explanation is and also what use the scientists made of this occurrence.

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Electrostatic induction in condensers. A metal plate *A* is mounted on an insulator and connected to an electroscope by a copper wire as shown in Figure 211. A similar plate *B* is connected to the earth by some grounded conductor, such as a gas pipe or water pipe. Let us charge *A* by touching it with a proof plane charged negatively and note the amount of divergence of the leaves of the electroscope. The electrons spread over the plate, the connecting wire, and the electroscope until all are at the same potential. Let us push *B* near to *A* but not close enough to touch. As *B* comes near *A*, the leaves on the electroscope begin to fall, showing that the potential of *A* is lowered. But since *B* has not touched *A*, no electricity is removed from the plate and the quantity remains the same. We can prove this by moving *B* away from *A*, thus causing the leaves on the electroscope to open to their former divergence. When *B* was brought near *A*, the electricity in *A*, which in this experiment was negative, repelled by induction the electrons from *B* to the ground, thus charging *B* positively. The positive charge on *B* attracted the electrons on *A* to the side nearest to plate *B*, thus drawing the electrons away from the electroscope and causing the leaves to fall together.

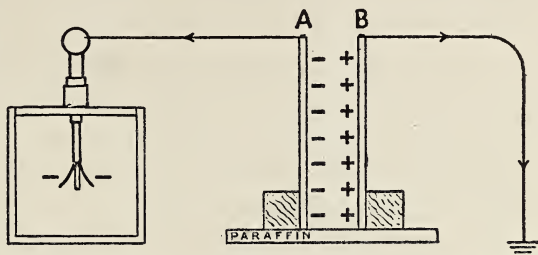


Fig. 211. Electroscope, mounted metal plates, and other apparatus for use in the experiment demonstrating electrostatic induction in condensers.

Let us push *B* near to *A* but not close enough to touch. As *B* comes near *A*, the leaves on the electroscope begin to fall, showing that the potential of *A* is lowered. But since *B* has not touched *A*, no electricity is removed from the plate and the quantity remains the same. We can prove this by moving *B* away from *A*, thus causing the leaves on the electroscope to open to their former divergence. When *B* was brought near *A*, the electricity in *A*, which in this experiment was negative, repelled by induction the electrons from *B* to the ground, thus charging *B* positively. The positive charge on *B* attracted the electrons on *A* to the side nearest to plate *B*, thus drawing the electrons away from the electroscope and causing the leaves to fall together.

If we use the proof plane to put electrons on *A* until the original divergence of the leaves is again produced, we find that many times the original quantity of electricity is required before we have enough on the electroscope. By noting how much is required we can determine the increase in capacitance of *A*. The divergence of the leaves will show when the potential is as great as it originally was. If we slide one plate sidewise without changing the distance between the plates, the increase in divergence of the

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leaves shows that the capacitance has been decreased. This proves that the capacitance of the condenser depends upon the size or area of the plates.

Capacitance and dielectrics. If a glass plate is slipped between *A* and *B*, the leaves will fall, and still more electricity must be put on *A* before the divergence is again the same, showing that with an insulating material between *A* and *B* the capacitance is greater than with a layer of air between them. By the use of thin layers of mica between the plates so that *A* and *B* can be brought very close together, the capacitance will be increased a great deal.

This arrangement, consisting of two or more conducting plates separated by nonconducting material, is called a condenser. The nonconductor is called a dielectric. The capacitance of a condenser depends upon the kind of dielectric used and on the distance between the conductors. It also depends on the areas of the plates separated by the dielectric. The capacitance of a condenser equals the quantity of electricity held by the plates divided by the P.D. between the plates, or $C = \frac{Q}{P.D.}$.

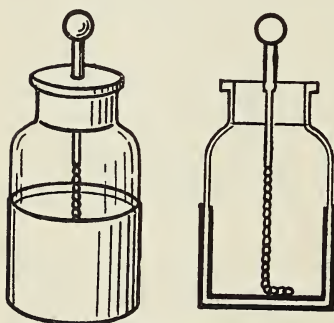


Fig. 212. Diagram showing the construction of a Leyden jar.

The Leyden jar. The Dutch scientist van Musschenbroek, mentioned on page 504, reasoned that, since a large quantity of electricity had accumulated in the glass jar, he could construct one for that specific purpose. Accordingly he made what is called the Leyden jar, still much used in experimental work and shown in Figure 212. It is a glass jar coated halfway up, inside and outside, with tin foil. A brass rod with a knob on

the upper end extends through the stopper, and the lower end of the rod is connected to the inner surface by a brass chain. To charge the jar, the knob is connected with one terminal of

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an electrical machine and the outside is grounded by means of holding the jar in the hand. The jar may be discharged by touching the knob with the other hand, but this method is not advised as the capacity of an ordinary quart-size jar is sufficient to give a severe shock. It should be done by connecting knob and outside coat with a discharging rod, Figure 213.

The dissectible type of Leyden jar consists of a brass outer vessel *A*, a large glass *B*, which fits inside of the outer vessel, and another brass vessel *C*, fitting inside *B* and having a curved rod with a knob on the end.

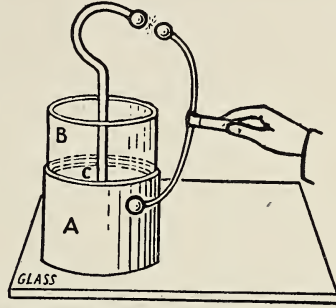


Fig. 213. Leyden jar that can be separated into three parts for experiment.

Variable condensers. The variable condenser, so called because its capacitance may be varied, consists of sets of stationary metal disks with alternate metal disks mounted on an axis rotating between them. Rotation of the movable disks varies the capacitance, since the area of the plates separated by the dielectric—air in this case—is thus made larger or smaller.

Condensers such as shown in Figure 214 are used in radio receiving sets. The rotation of the disks is accomplished by one of the dials. In the timing magneto of an airplane engine, condensers play an important part in the effective operation of the ignition system. Condensers consisting simply of strips of tin foil separated by paraffined paper are used in radio receiving sets, in the spark coils of automobiles, and in other electrical devices.

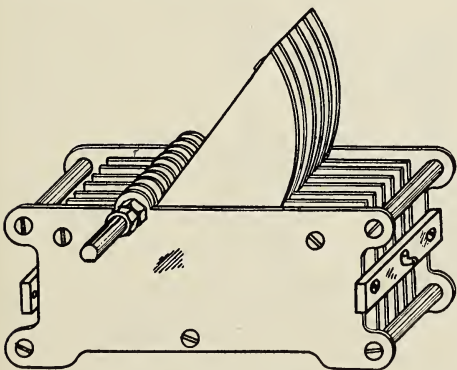


Fig. 214. Diagram of a variable condenser.

The electrophorus. The electrophorus is a device for producing electricity by

MISCHIEF-MAKERS AMONG ELECTRONS

induction. It was invented by Volta in 1777. For experimental purposes, the electrophorus, Figure 215, consists of a

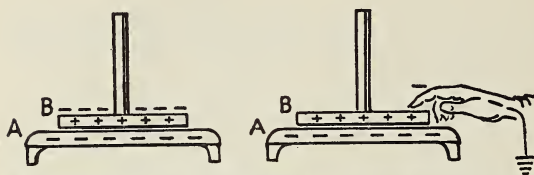


Fig. 215. Drawing of experiment with an electrophorus.

hard rubber plate *A* or some other insulator and a metal plate *B*, with a handle of some insulating material. Plate *A* is rubbed with fur or flannel and thus given a negative

charge. If plate *B* is now placed on the plate *A*, electrons will be repelled from the lower surface of the metal plate *B* to the upper surface. The touch of a finger, as illustrated in Figure 215, will lead off the electrons into the ground. The plate *B* will then have a positive charge by induction. If we lift the disk *B*, the knob of a Leyden jar will draw a short electric spark. We can then return it to plate *A* and repeat the operation. This can be done again and again, strongly charging the jar.

The Wimshurst electrical machine. The Wimshurst machine, shown in Figure 216, produces electricity by induction. When the ter-

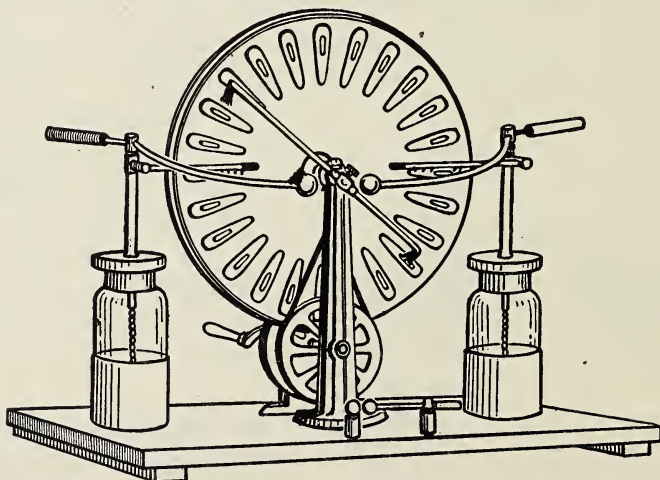


Fig. 216. Diagram showing essential parts of the Wimshurst machine.

minals are separated, a large potential difference is built up by this machine. To produce a spark one centimeter long, about 30,000 volts of potential difference is required. A large machine produces a spark several inches long. While it produces a high voltage, the current it produces is very small. The Wimshurst machine, producing little electrical energy, is used for demonstration purposes only.

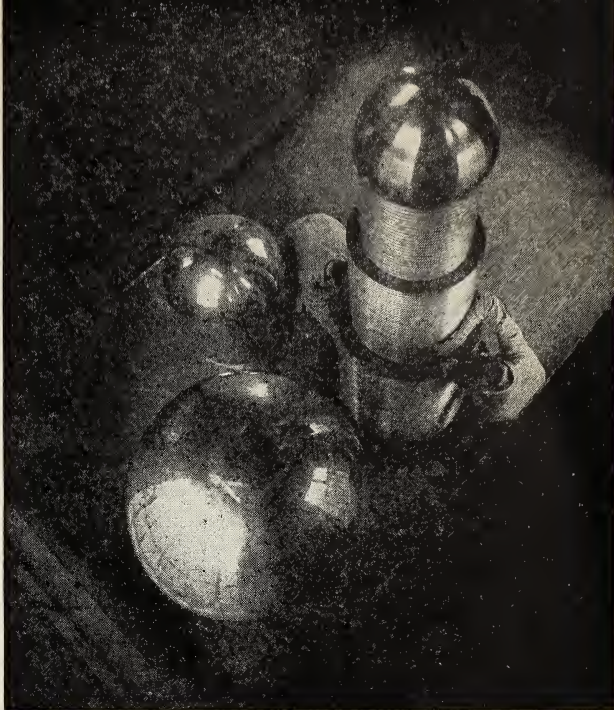
The electrostatic generator.

The electrostatic generator is a machine that can generate many times the voltage possible with a Wimshurst machine.

It was devised at the Massachusetts Institute of Technology by Professor Van de Graaff. It consists of two large metal shields insulated from the ground by two supporting columns 30 feet high. Inside these columns are motor-driven endless belts of rubber that carry charges up to the shields and charge them on the outer surface to a potential difference of 5,000,000 volts or more. This voltage can be discharged through vacuum tubes and, as we shall see later, is used in atom smashing.

A modification of the Van de Graaff generator has been devised by Dr. John G. Trump, also of the Massachusetts Institute of Technology. This consists of a tower thirteen feet high of alternate rings of metal and insulating material. At the top of this tower is a dome-shaped high-voltage terminal of metal that is two feet in diameter.

A belt of insulating material twelve inches wide travels at high speed within the column. The function of this belt is to carry



Ferdinand Hirsh

Assembling the 4,000,000-volt generator, Massachusetts Institute of Technology. The shields at the left are placed over the column, one within the other.

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an electrical charge created by friction at the base of the tower to the terminal at the top. In the tower is a mixture of Freon gas and air under pressure. The purpose of this mixture is to increase the insulating qualities of the tower and make possible 4,000,000 volts without electrical breakdown.

ANSWER THESE QUESTIONS

1. What is the smallest charge of electricity?
2. What is a coulomb?
3. What is meant by potential?
4. How is potential difference measured?
5. What is the unit of capacitance?
6. How does a condenser work?
7. How may the capacitance of a condenser be increased?

SUMMARY

Static electricity is electricity created by friction. Benjamin Franklin began scientific work on the subject. It was he who discovered the properties of negative and positive charges. Today scientists have acquired an exact knowledge of the nature and potentialities of this once mysterious force.

An electroscope is an instrument used to detect electrical charges. Its construction is based on the principle that like charges repel and unlike charges attract. A body is charged by the removal of electrons from it or by the addition of electrons to it. A body may be charged by conduction when it is brought into contact with another charged body. A body may be charged by induction, in which case its charge will be opposite to the charge in the charging body.

In conductors, such as most metals, the electrons are held in the atoms by a slight attraction between the electrons and nucleus and are free to move easily from atom to atom. In nonconductors, or insulators, the electrons and nucleus have a very strong attraction for each other, and the electrons are not free to move from atom to atom. Electrical charges on a body are on the outside

of it and are greatest in number where the curvature of the body is most abrupt.

Lightning is an electrical discharge from cloud to cloud or from cloud to earth. The modern lightning rod is a device used on buildings to prevent fire resulting from lightning. It functions by conducting the lightning charge into the ground. Precautions should be taken by every individual to avoid danger in violent electrical storms.

An elementary charge of electricity is a charge of one electron. An electrostatic unit of charge is that quantity of electricity which, when placed one centimeter away from an exactly equal and similar charge, will repel it with a force of one dyne. A coulomb is a larger and more practical unit of electricity and is equal to three billion electrostatic charges. The ampere is the unit by which the rate of flow of electrons through a conductor is measured. One ampere is the flow of a coulomb of electricity past a given point in one second. Potential is the electrical pressure at a given point in a conductor. Potential difference is the difference of electrical pressure between two points. The unit of potential difference is called a volt. Capacitance is the quantity of electricity per unit of potential difference. The unit of measurement of capacitance is a farad. A farad is the capacitance of a conductor into which a coulomb of electricity may be put with a potential difference of one volt. Because the farad is an extremely large unit, a microfarad, or one-millionth of a farad, is most generally used in the measurement of capacitance.

A condenser is a device to increase the quantity of electricity that can be stored at a given difference of potential. The capacitance of a condenser depends upon the cross-sectional area of the plates, their distance apart, and the material of which the dielectric is made.

If a person walks across a woolen carpet in winter and then touches a piece of metal, he often sees and feels an electric spark. Why is this? In the summertime there is no spark. Can you explain?

When an ebonite rod is charged with a piece of fur, why is there no charge noticed on the fur?

MISCHIEF-MAKERS AMONG ELECTRONS

How can an electroscope be charge by conduction? by induction?

What are several good conductors of electricity? several non-conductors?

What is the purpose of lightning rods? Explain how they work.

Why do gasoline trucks have chains dangling from them to the ground? Why do not automobiles have the same equipment?

Where are the safest places during an electrical storm?

Where are condensers commonly used?

INVESTIGATIONS

1. Visit a factory where steam passes through long pipes to see how they prevent large static charges on the pipe. Also examine machine-driven belts to see how large static charges are prevented.

2. Examine the insulation of lightning rods on a barn or house to see how they are grounded. Do not do this during an electrical storm.

3. Examine and take apart a discarded radio condenser to discover how it is constructed.



The man in this picture is able to contact people many miles away by means of the telephone. The operation of the telephone depends upon the rapid flow of electricity in motion.

Pioneer Workers among Electrons

DIRECT-CURRENT ELECTRICITY

After your study of static electricity in the last unit you are now ready to consider current electricity, or electricity in motion, the type of electricity that makes possible the telephone shown in the picture above. Only when electricity is in motion does it do useful work in the world, such as turning the wheels of factories, running railroad trains, sending messages by wire,

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lighting buildings and streets, and providing heat for industrial furnaces and kitchen stoves. Thus millions of people are concerned daily with electricity in motion, using it to satisfy their needs in a variety of ways.

There are two kinds of current electricity, direct current and alternating current. The first type of current electricity was discovered in 1796 by an Italian named Alessandro Volta. This famous scientist discovered that when two kinds of metal are placed in certain fluids and connected with an external circuit an electric current flows through the circuit. This current is called a direct current because the electrons continuously flow in the same direction, much as water flows through a pipe.

The second type of electricity was discovered by Joseph Henry of this country in 1830 and Michael Faraday of England in 1831. These famous scientists found that when a conductor cuts across a magnetic field an electric current is produced. This kind of current is called alternating current because the electrons change their direction of flow every time a change occurs in the relative motion between the conductor and the magnetic field. Following the discovery of alternating current, the dynamo was developed for producing both direct and alternating current. Since direct current was discovered first, you may think of the electrons which produce direct current as the pioneer workers in the field of current electricity.

For a time direct current was much more widely used than alternating current because it was better understood and easily produced. Finally the time came when electricity needed to be transferred for long distances over wires, and it was discovered that alternating current could be transferred more economically than direct current. Thus today about 95 per cent of the current electricity is alternating current.

In this unit you will study direct-current electricity and the manner in which such electricity behaves. From this study you will learn the basic, or underlying, principles of current electricity and thus lay the foundation for a special consideration of alternating current in the succeeding unit.

DIRECT CURRENT LIKE FLOWING WATER

AREAS OF STUDY

1. *In what ways is a direct current of electricity like flowing water?*
2. *How is the resistance of a direct-current conductor measured?*
3. *How can a direct current be produced by chemical action?*
4. *What effects are produced when a direct current of electricity passes through a liquid conductor?*
5. *What is meant by electric power?*
6. *How is electrical energy changed into heat energy or light energy?*
7. *How is the magnetic effect of a direct current used?*
8. *How is mechanical energy changed into electrical energy?*
9. *How is electrical energy changed into mechanical energy?*
10. *How may an electromotive force be induced in a conductor without perceptible motion?*

AREA ONE

In What Ways Is a Direct Current of Electricity like Flowing Water?

Electricity is so widely used today that most persons know something about it. They know that it flows over wires and that it provides power, light, and heat. They know also that they can ring a doorbell by pushing a button or turn on lights by

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operating a switch. For intelligent use of electricity, however, a person must know what electricity is and how it moves from one place to another.

An electric current a flow of electrons. An electric current may be considered a flow of electrons along a conductor. The flow occurs because of a difference in electrical potential, which is merely a term for electrical pressure. Thus the flow of electricity may be compared with the flow of water in a pipe, which occurs because of a difference in pressure. If we examine the upper drawing in Figure 217, we can readily see how a difference in water pressure works. The pump at the right increases the pressure at the first pressure gauge, causing it to be higher than the pressure at all the

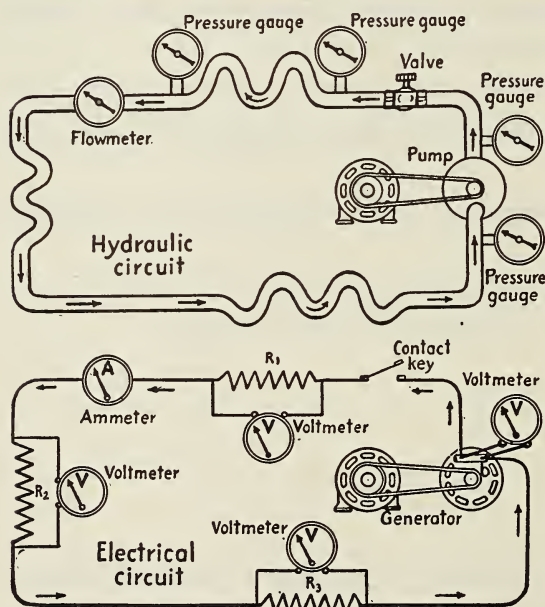


Fig. 217. Diagrams of a water pump and an electric generator, illustrating similarity of the conditions of flow.

other pressure gauges in the circuit. The difference in pressure causes the water to flow completely around the circuit, as indicated by the arrows. The flow continues as long as the pump maintains a difference in pressure in the circuit.

The lower drawing in Figure 217 shows how an electrical circuit compares with a water circuit. An electric current flows as indicated by the arrows because a generator at the right causes the

potential at the first voltmeter to be higher than the potential at other points in the circuit. The current at the first voltmeter has a high potential, and other points along the circuit have lower

DIRECT CURRENT LIKE FLOWING WATER

potentials. The difference in potential, commonly expressed as P.D., in an electrical circuit is known as the electromotive force, or e.m.f., which is the same as electrical pressure.

From the foregoing we find that an electric current always flows from a point of high potential to a point of low potential. The point of high potential in a generator or storage battery is the negative terminal; hence, when either a generator or a storage battery is attached to a circuit, the electricity flows from the negative terminal to the positive terminal. Care must be taken to keep this direction of flow definitely in mind, for since the days of Franklin it has been customary to speak of a current of electricity as flowing from the positive to the negative. Even though this statement is erroneous, it has been deeply entrenched in all scientific literature, too deeply entrenched to change. Consequently, when we speak of an electric current as flowing from the positive to the negative, we mean exactly the reverse; that is, from the negative to the positive.

When water flows through a water system as illustrated in Figure 217, it meets resistance from friction where the pipe is small or crooked. The smaller the pipe or the more crooked it is, the greater the resistance. Likewise an electric current meets resistance when it flows through a circuit. The quantity of this resistance depends upon the length, size, and temperature of the conductor and the material of which the conductor is made.

What determines the rate of flow? If we wish to increase the rate of flow in a water system such as shown in Figure 217, we may (1) use a larger pump or run the pump faster or (2) use straighter or larger pipes and thus reduce the friction. Similarly, if we wish to increase the rate of flow in an electrical circuit, we may (1) increase the electromotive force, or e.m.f., or (2) reduce the resistance. The rate of flow, or strength of a current, is measured in amperes, an ampere being a unit of strength. The difference in potential is measured in volts, a volt being a unit of potential difference. The resistance in a circuit is measured in ohms, named after the German scientist Georg Simon Ohm. An ohm is the



Georg Simon Ohm
(1787-1854)

Ohm was a distinguished German physicist. He was born at Erlangen and was educated at the university there. Most of his researches in physics were related to electric currents and conductors. He is best known for the formulation of Ohm's law concerning the relations of current to electromotive force and resistance. The international unit of resistance, the ohm, is named after him.

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resistance offered to a potential difference of one volt producing a current of one ampere. Expressed otherwise, an ohm is the resistance offered by a column of mercury 106.3 centimeters high with a cross section of one square millimeter at 0° Centigrade.

The relation of the strength of a current, or rate of flow, the electromotive force, or e.m.f., and the resistance is expressed in a law known as Ohm's law. This law is commonly expressed as follows: *The electric current in a circuit is directly proportional to the electromotive force and inversely proportional to the resistance.* Expressed in the form of an equation, the law is as follows:

$$\text{Strength of current} = \frac{\text{electromotive force}}{\text{resistance}}$$

Since the strength of the current, as indicated above, is measured in amperes, the electromotive force, or e.m.f., in volts, and the resistance in ohms, the equation may be written as follows:

$$\text{Amperes} = \frac{\text{volts}}{\text{ohms}}$$

If the strength of current, or rate of flow, is represented by I , electromotive force by E , and resistance by R , the equation is:

$$I = \frac{E}{R}$$

Ohm's law is valid not only for a complete circuit but also for any part of the circuit, as in the circuit shown in Figure 217.

DIRECT CURRENT LIKE FLOWING WATER

When so applied it is more correctly written as:

$$I = \frac{P.D.}{R},$$

where *P.D.* represents the difference in potential between the given points, and *R* represents the resistance of the conductor connecting the points.

A simple circuit. Figure 218 represents a simpler circuit than the electrical circuit in Figure 217. Let us apply these fundamental relations to it. The cell furnishes the electromotive force (e.m.f.) of the circuit. The ammeter *A* shows the quantity of current traveling through the circuit. Because there is just one path for the electrons to follow in the whole circuit, the rate of flow must be the same at all points. The ammeter is said to be connected in series with the remainder of the circuit.

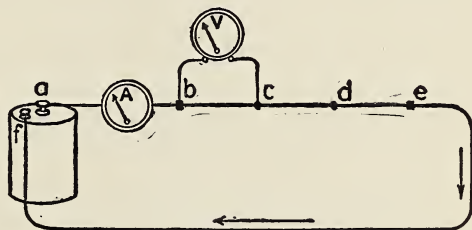


Fig. 218. Diagram showing operation of a simple circuit. The arrows indicate the direction of flow.

The voltmeter *V*, with its connecting wires, forms another path for some of the current to flow between the points *b* and *c*. It is said to be connected in parallel with *bc*. Later when we study the voltmeter we shall learn that only a very small current flows through it. That part of the circuit from the point *a* where the electric current comes out of the cell to the point *f* where the current returns to the cell is called the external circuit. The voltmeter, as connected in the figure, indicates the fall of potential, or potential difference (*P.D.*), between the points *b* and *c*. It is this difference in potential that makes possible the pressure which causes the current to flow from *b* to *c*.

Fall of potential along a conductor. If the terminal of the voltmeter now at *c* is moved to *d*, the voltmeter shows a greater potential difference, and if it is moved to *e* it shows a still greater

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potential difference. This is to be expected because the current flows a greater distance through the conductor from *b* to *d* than from *b* to *c*, and its flow meets more opposition or resistance in the longer distances. Ohm's law tells us that the fall of potential (P.D.) from *b* to *c* depends upon the current flowing and the resistance of the conductor over which it flows, or:

$$\text{P.D.} = I \times R, \text{ or } IR.$$

We may also increase the fall of potential between two points in the circuit by increasing the current in the circuit. We may do this by increasing the total e.m.f. of the circuit, by using more dry cells, or by decreasing the resistance of the circuit. If that part of the conductor from *d* to *e* is eliminated by connecting at *d* instead of at *e*, the ammeter will show that more current is flowing and the voltmeter connected to *b* and *c* will show a higher reading. We may find the resistance from *b* to *c* by dividing the voltmeter reading (P.D.) by the ammeter reading *I*.

Example. What is the fall of potential across an electric toaster whose resistance is 20 ohms when it is using 5.5 amperes?

Solution. $\text{P.D.} = IR.$

$$\text{P.D.} = 5.5 \times 20 = 110 \text{ volts.}$$

ANSWER THESE QUESTIONS

1. What is a direct current of electricity?
2. How is the flow of a direct current like the flow of water?
3. What kind of energy does the flow of a direct current have?
4. What kind of electricity flows in a solid conductor?
5. What is the direction of the electric flow?
6. When we speak of the direction of the flow of current, what direction is meant?
7. In the upper part of Figure 217 in what two ways can the rate of flow of the water be increased?
8. In the lower part of Figure 217 in what two ways may the current be increased?
9. How can Ohm's law be stated in words?
10. How can Ohm's law be expressed in three equations?
11. How can the fall of a potential between two points in a circuit be read?

RESISTANCE OF A DIRECT-CURRENT CONDUCTOR

SOLVE THESE PROBLEMS

1. How much current will flow through an electric lamp that has 460 ohms resistance, when 115 volts are applied?

2. What is the drop in voltage from the generator to the lecture table when 10 amperes of current are used, if the resistance of the wires is 0.2 ohm?

3. If an electric toaster has a resistance of 20 ohms, what current will it take on a 115-volt circuit?

4. A telegraph sounder has a resistance of 4 ohms. How many volts must be applied to its terminals to send 1.5 amperes through it?

5. What is the resistance of an electric lamp that takes 0.35 ampere when 115 volts are applied?

6. A voltmeter has a current of 0.010 ampere when it reads 100 volts. What is its resistance?

7. What is the resistance of an electric iron if a 5-ampere current is used on a 115-volt circuit?

8. What will be the reading of a voltmeter connected across the terminal of a lamp when the resistance of the lamp is 230 ohms and it takes a 0.5-ampere current?

9. Eighty 60-watt lamps 400 feet from a generator whose voltage is 125 volts are to be supplied with 40 amperes of current at a voltage of 120 volts. What is the line drop allowed? What is the resistance of the connecting wires? What would be the resistance of 1000 feet of the same wire? Find from Table XII in the Appendix the number of the copper wire that should be used.

AREA TWO

How Is the Resistance of a Direct-Current Conductor Measured?

We have learned long since that science is concerned with accurate measurement and that measurement is the key to many discoveries and applications of scientific principles. Measurement is particularly important to the study of electricity because it is one of the chief means of describing electrical phenomena. In this area we shall study the data and some of the different techniques that are used to measure the resistance offered by a conductor to the flow of electricity.

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METHODS OF MEASURING RESISTANCE

Measuring the resistance of a conductor by the voltmeter-ammeter method. As has been shown on page 519, the rate of flow of a current may be measured by an ammeter, and the fall of potential, or electromotive force, may be measured by a voltmeter. Resistance, however, is not measured directly but calculated. To do this we use Ohm's law. We have learned that Resistance =

$\frac{\text{P.D.}}{\text{current}}$. Now let us suppose that we wish to

find the resistance of an electric bell. Let Figure 219 represent the electrical circuit used. From the ammeter we get the current flowing through the bell in amperes, and from the voltmeter we get the P.D. across the terminal of the bell in volts. We find the resistance by dividing the number of volts by the number of amperes.

The voltmeter-ammeter method is used in finding the resistance of many electrical appli-

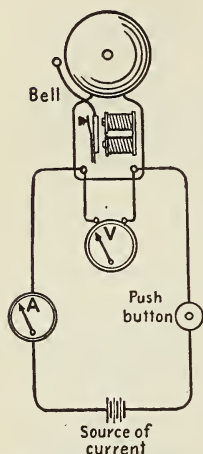
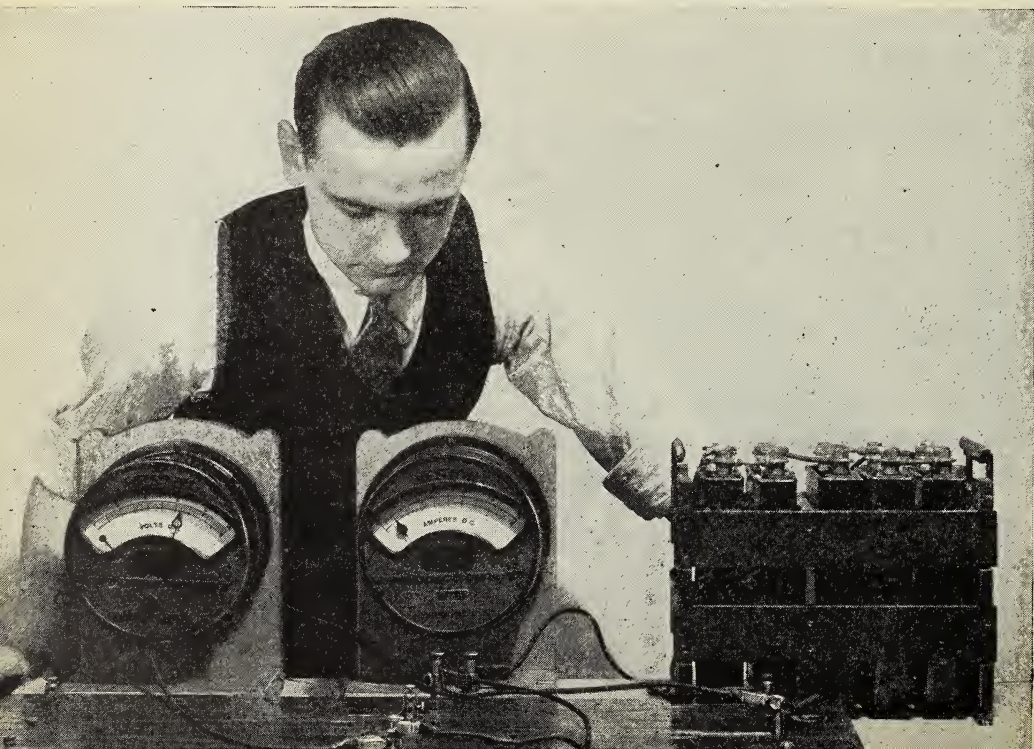


Fig. 219. Diagram of an electric-bell circuit.

The student in this picture is determining the resistance of a conductor by the voltmeter-ammeter method. He is using a storage battery to generate electric current.



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ances such as the electric iron, electric toaster, and electric lamp. Despite the fact that the method is extremely simple, it lacks something in accuracy and hence is not employed where great accuracy is required. In many kinds of industry other methods are used which provide much greater accuracy. One of these methods is the Wheatstone bridge method, which is explained in the following paragraphs.

Measuring resistance by the Wheatstone bridge. Another method of measuring resistance is by means of an instrument known as the Wheatstone bridge. This instrument, as shown in Figure 220, consists of four sides with provision for dividing a current into two parts. Three sides of the bridge contain resistance boxes, by which known resistances indicated by R_1 , R_2 , and R_3 may be applied. The fourth side of the bridge contains the object of unknown resistance indicated by R_4 and, since it is unknown, also indicated by X . When the key k_2 is closed, causing a current to flow in the bridge, the current divides at point b into two currents, the first current, I_1 , going by way of c to point d , and the second current, I_2 , going by way of a to point d . By adjusting the resistance boxes and setting up known resistances R_1 , R_2 , and R_3 , we may make the potential at point c equal to the potential at point a . The bridge is balanced because no current flows through the galvanometer attached to the circuit and the reading is zero. When the bridge is balanced, the following relationship exists:

$$R_1 : R_2 :: X \text{ (unknown resistance)} : R_3.$$

From this equation we obtain the following equation, known as the equation of the Wheatstone bridge:

$$X = \frac{R_1 R_3}{R_2}.$$

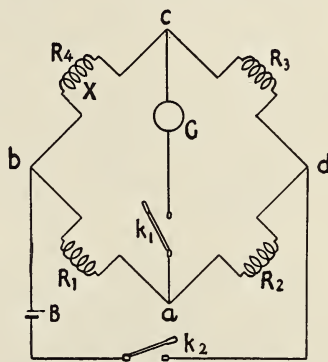


Fig. 220. Diagram showing the parts and wiring of a Wheatstone bridge.

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Another type of Wheatstone bridge found in many school laboratories is the slide-wire bridge shown in Figure 221. This bridge, like the first, consists of four sides, the sides *a* and *b* being made of straight, uniform wire.

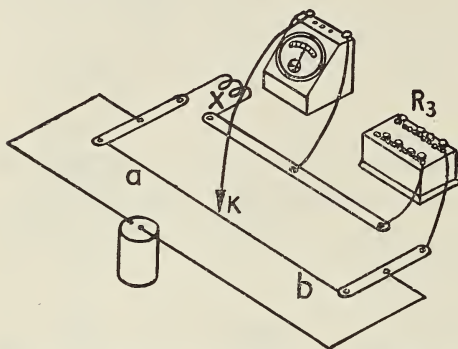


Fig. 221. Diagram showing part. of a slide-wire bridge. The current is furnished by a dry cell.

The circuit contains one resistance box and also the object of unknown resistance indicated by *X*. Between the two is a galvanometer made to register zero by sliding terminal *k* along wire *ab*. Since the wire is of uniform diameter, we may substitute the lengths *a* and *b* for *R*₁ and *R*₂ respectively in the foregoing equation, thus obtaining the following equation:

$$X = \frac{aR_3}{b}.$$

The Wheatstone bridge and the measurement of temperature in aviation. The principle of the Wheatstone bridge is used in constructing the electric thermometers of airplanes. This device consists of four sides, three sides of which are inclosed in the registering portion and the fourth side of which contains an incased part, known as a resistance bulb, exposed to free air. The inner part of this bulb consists of wire wound around a small tube, as shown in Figure 222. When this wire has the same temperature as the other three sides of the bridge, it offers the same resistance to an electric current as the other three sides. In other words, the bridge is balanced, and the indicator on the dial stands at zero. When the resistance bulb comes into contact with air of higher temperature its resistance increases, and when it comes into contact with air of lower temperature its resistance decreases and the bridge is thrown out of



Fig. 222. Drawing of a resistance bulb used in a Wheatstone bridge.

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balance. The lack of balance causes the pointer to move over the dial, which is calibrated to show the temperature directly.

The Wheatstone bridge and fuel-air ratio. The principle of the Wheatstone bridge is also used in testing the exhaust gas of airplane engines. The nature of this gas is very important, for it indicates whether the mixture of fuel gas entering the cylinders is too rich or too lean. The Wheatstone bridge in this case consists of four sides, each of which contains a platinum resistance coil, as shown in Figure 223.

Two of the coils, *A* and *C*, are exposed to the air, and the other two, *B* and *D*, to the exhaust gas. When all the resistance coils have the same temperature, the bridge is balanced and the indicator on the dial stands at zero. If the gas contains an abundance of carbon dioxide, as when the engine operates on a lean mixture, less heat passes off from coils *B* and *D* than from coils *A* and *C*, because carbon dioxide is a poorer conductor of heat than

air. Coils *B* and *D* thus rise in temperature, offer greater resistance to the flow of electricity, and throw the bridge out of balance. The lack of balance causes the pointer to move over the dial, which is calibrated to show rich fuel-air ratios on one side and lean fuel-air ratios on the other. If the gas contains less carbon dioxide, as when the engine operates on a rich mixture, coils *B* and *D* offer less resistance and the pointer moves in the other direction on the dial. The resistance of an electric current thus helps the pilot to know whether his engine is receiving the right fuel-air mixture.

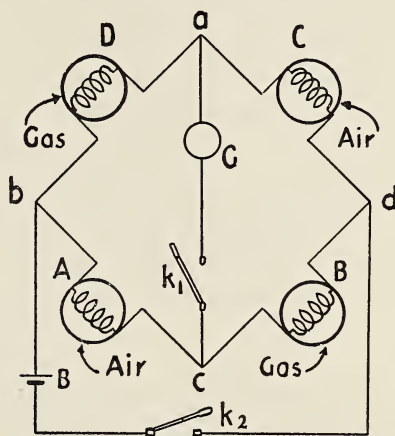


Fig. 223. Diagram showing adaptation of the Wheatstone bridge to measure fuel-air ratios.

Laws of resistance. The law of length is as follows: *The resistance of a conductor is directly proportional to its length.* This means that

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10 feet of wire has twice as much resistance as 5 feet of the same wire. Expressed in another way, the resistance of two conductors of the same size and material, provided the temperature remains the same, is directly proportional to their respective lengths.

Expressed algebraically, the law of length becomes $\frac{R_1}{R_2} = \frac{L_1}{L_2}$,

where R_1 represents the resistance of the first wire, R_2 the resistance of the second wire, L_1 the length of the first wire, and L_2 the length of the second wire. The length of wires in the United States and Great Britain is generally expressed in feet.

The law of size is as follows: *The resistance of a conductor is inversely proportional to its cross-sectional area or to the square of its diameter.* This means that the larger a wire is, the less is its resistance. If R_1 and R_2 represent the resistances of two wires of the same length and material, D_1 and D_2 the diameters, and A_1 and A_2 the cross-sectional areas, the law of resistance may be written as follows:

$$\frac{R_1}{R_2} = \frac{D_2^2}{D_1^2} = \frac{A_2}{A_1}.$$

Manufacturers of wire often express the diameters of wires in mils and the cross-sectional areas in circular mils. A mil is $\frac{1}{1000}$ inch, and a circular mil is the area of a circle having a diameter of one mil. A wire that has a diameter of two mils has a cross-sectional area of four circular mils. The square of the diameter in mils, then, is equal to the cross-sectional area in circular mils. This system of measurement saves time in calculating areas.

Substances differ in their conductivity of electricity. Metals are generally good conductors, but they vary greatly in respect to the resistance they offer to the passage of electrons through them. Silver is the most satisfactory conductor, copper is second best, and aluminum third. Alloys such as German silver, manganin, and nichrome have a high resistance.

Resistivity, or specific resistance. Each substance has a resistance constant. This resistance, K , or, as it is sometimes called, specific resistance, is the resistance offered by a wire one foot long and

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one mil in diameter, which is known as a mil-foot of a substance. The following table indicates values of K for some of the conductors commonly used.

	<i>Ohms per Mil-Foot</i>		<i>Ohms per Mil-Foot</i>
Silver	9.74 ohms	German silver	180–218 ohms
Copper	10.4 ohms	Manganin....	280 ohms
Aluminum ...	17.7 ohms	Nichrome....	660 ohms

Effects of temperature on the resistance of metallic conductors. If we wind about 10 feet of fine iron wire about a piece of asbestos, connect the wire in series with an ammeter, and then heat the coiled wire with a Bunsen burner as shown in Figure 224, we find that the resistance increases with an increase of temperature. Similarly, the resistance of all metallic conductors increases with an increase in temperature and decreases with a decrease in temperature. Lead, for example, at a temperature of -270° Centigrade has been found to offer practically no resistance to electricity. On the other hand, there are some substances in which the resistance decreases when the temperature is increased. Among these

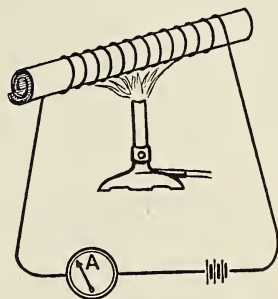
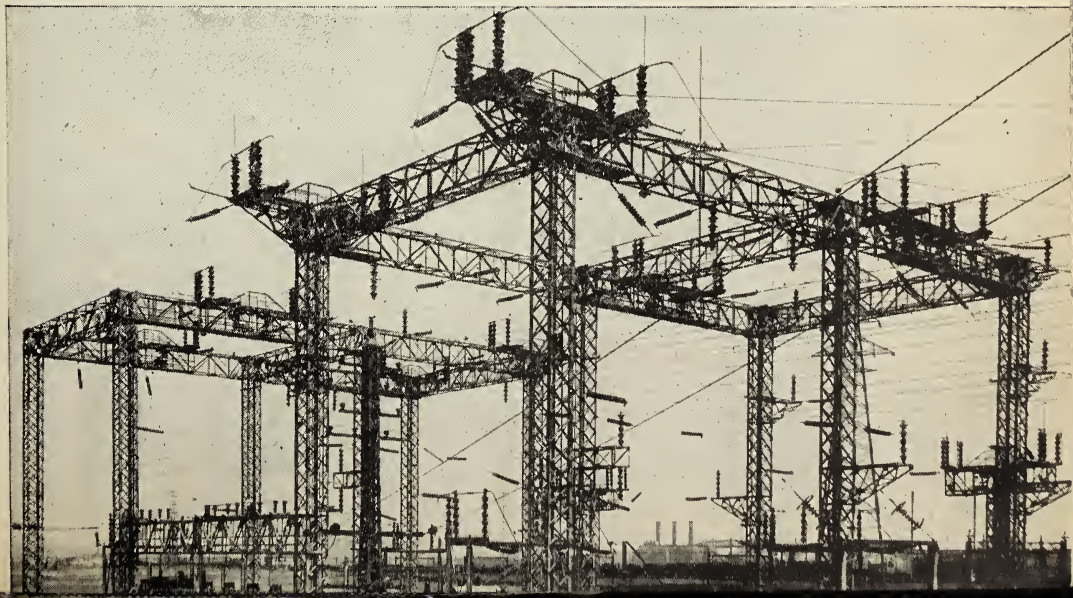


Fig. 224. Experiment to show the effect of heat on resistance.

This picture shows the complicated wiring at a large power transmission station. This particular station receives 132,000 volts and reduces it through transformers to about 11,000 volts. In this process the resistances of various materials are vital factors.

Ewing Galloway



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are certain nonmetals, such as carbon, glass, porcelain, and various solutions of acids, bases, and salts. For example, a carbon-filament lamp offers less resistance in its filament when the filament is hot than when it is cold.

The rate at which the resistance of a conductor changes per ohm per degree change in temperature is called the temperature coefficient of resistance of the substance of which the conductor is composed. The resistance of a copper coil of wire whose resistance is one ohm at 20° Centigrade increases at the rate of 0.00393 ohm for each 1° Centigrade increase in temperature above 20° Centigrade. The temperature coefficient of all pure metals is nearly the same, but of certain alloys it is very small, that of manganin being as low as 0.00001 for each degree Centigrade. For this reason manganin is used in the manufacture of electrical measuring instruments such as ammeters and voltmeters. For designers of devices for transforming electrical energy into heat energy, the temperature coefficient of resistance is important.

One law from several. By combining what we have learned about the effect of length, diameter, and material on the resistance of a conductor, we can compute its resistance. If its length in feet, its diameter in mils, and its material are known, one can find its resistance by multiplying its length in feet by its resistance per mil-foot and dividing by the square of its diameter in mils.

Expressed algebraically, $R = \frac{KL}{D^2}$ where K is the resistance per mil-foot, L is the length in feet, and D is the diameter in mils.

Example. A nichrome wire is 3 feet long and 10 mils in diameter. K for nichrome is 660 ohms. Then $R = \frac{KL}{D^2}$ becomes $R = \frac{660 \times 3}{10 \times 10} = 19.8$ ohms. This is used as a check on the resistance found by dividing the P.D. by the current. A wire of German silver is 3 feet long and 14 mils in diameter. Its resistance is $R = \frac{180 \times 3}{196} = 2.75$ ohms.

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(Note. To find the resistance when the metric system is used, the formula is: $R = \frac{KL}{A}$. K is the resistance constant for one square centimeter area one centimeter long, A is the area in square centimeters, and L is length in centimeters.)

TYPES OF ELECTRICAL CIRCUITS

Series circuits. To understand the flow of current in series circuits, let us examine a series circuit of three lamps, the lamps offering different resistances. Three ammeters, (1), (2), and (3), show the strength of the current, or the rate of flow, at three different points in the circuit, as shown in Figure 225. All the ammeters read the same, showing that the rate of flow is the same at all the points. This situation exists because there is only one path for the current, and therefore the rate of flow cannot be greater at one point than at another. From this experiment we may conclude that the rate of flow of a current in a series circuit is the same in every part.

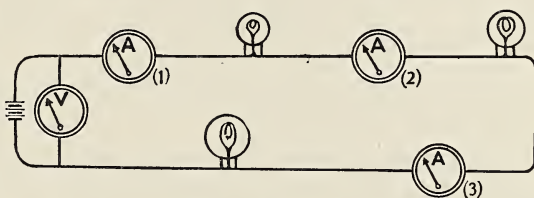


Fig. 225. Diagram of series circuit arranged for testing flow of current at three points of different resistance.

Now let us note the fall of potential in a series circuit by examining a series circuit of three lamps of different resistances,

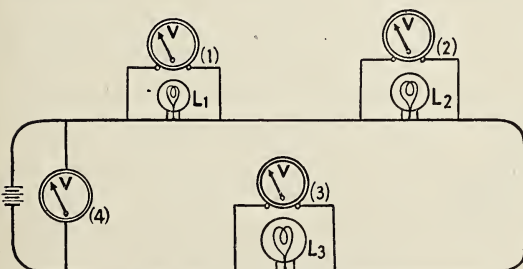


Fig. 226. Series circuit arranged for measuring fall of potential at different points and in the whole circuit.

with a voltmeter across each lamp and another one across the circuit, as is illustrated in Figure 226. The readings of the voltmeters across the lamps differ, showing that the voltage or fall of potential across the

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lamps is not the same. The voltmeter across the smallest lamp shows the greatest voltage, or the greatest fall of potential, which indicates that this lamp offers the greatest resistance. The voltmeter across the largest lamp, on the other hand, shows the smallest voltage, which indicates that this lamp offers the least resistance. From these observations we may conclude that in a series circuit the voltage, or fall of potential, across the different parts is directly proportional to the resistance of the parts. If we examine the voltmeter across the complete circuit, we find that its reading equals the sum of the readings of the voltmeters across the different lamps. From this observation we may conclude that the total voltage in a series circuit is equal to the sum of the voltages of the parts. If we find the resistance of each lamp by applying

Ohm's law, $R = \frac{P.D.}{I}$, and then add the resistances, we find that the total resistance in the circuit is equal to the sum of the resistances of the parts.

To summarize from the foregoing, we have gathered the following information about a series circuit: (1) the current, or rate of flow, is the same at all points; (2) the voltage, or fall of potential, across the different parts is directly proportional to the resistance of the parts; (3) the total voltage in the circuit is equal to the sum of the voltages of the parts; and (4) the resistance in the circuit equals the sum of the resistances of the parts.

Parallel circuits. To understand the flow of current in parallel circuits, let us examine a parallel circuit of two lamps, as shown in Figure 227. Ammeter (1) registers the current in the complete

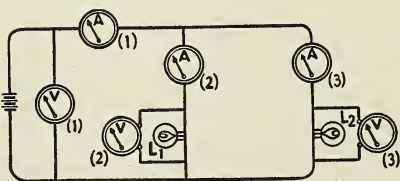


Fig. 227. Diagram of divided circuit used for measuring potential difference in each branch.

circuit; ammeter (2) the current through the first lamp; and ammeter (3) the current through the second lamp. Voltmeter (1) registers the voltage, or fall of potential, across the complete circuit; voltmeter (2) the voltage across lamp L_1 ; and voltmeter

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(3) the voltage across lamp L_2 . First let us examine the circuit when two similar lamps are used, such as two 25-watt lamps. In this case ammeters (2) and (3) indicate the same rate of flow, and voltmeters (2) and (3) indicate the same voltage. The reading of ammeter (1) equals the sum of the readings of ammeters (2) and (3), but the reading of voltmeter (1) is the same as the reading of voltmeter (2) or the reading of voltmeter (3). Next let us examine the circuit when two dissimilar lamps are used, such as a 25-watt lamp and a 40-watt lamp. In this case ammeter (3) registers more than ammeter (2), showing that the second lamp is getting more current than the first. Voltmeter (2) again indicates the same voltage as voltmeter (3). The reading of ammeter (1) equals the sum of the readings of ammeters (2) and (3). Voltmeter (1) again registers the same as voltmeter (2) or the same as voltmeter (3).

This experiment shows that in a divided circuit the potential difference (P.D.) across each branch is the same. It also shows that the total current flowing is equal to the sum of the currents flowing in the branches. If we observe the total resistance of the

circuit, $\frac{V_1}{A_1}$, and the resistance of each lamp when the lamps are

alike, $\frac{V_2}{I_2}$ and $\frac{V_3}{I_3}$, we find that the total resistance exactly equals

one-half the resistance of each lamp. If we repeat these observations when the lamps are unlike, one 25-watt and the other 40-watt, we find that the total resistance of the circuit is less than the resistance of either lamp, the 40-watt lamp offering less resistance than the 25-watt lamp.

If the conductors in a parallel circuit are alike, or similar conductors, we find their combined resistance by dividing the resistance of any one conductor by the number of conductors. In case we arrange two wires in a parallel circuit, for example, each with a resistance of 12 ohms, we find their combined resistance by dividing 12 by two. In case we arrange three wires in a parallel circuit, each with a resistance of 12 ohms, we find their combined resistance by dividing 12 by three.



Century Photos, Inc.

The worker in this picture is wiring one of the outlets in a household electrical circuit. The various outlets of this circuit are connected in parallel.

If the conductors in a parallel circuit are unlike, or dissimilar conductors, we can find their combined resistance by dividing the potential difference by the sum of their currents. We find the combined resistance of part of the conductors in a circuit by dividing one volt by the sum of their conductances. By conductance we mean the rate of flow measured in amperes when a potential difference of one volt is applied to the conductor. An example will help make this clear. Let us find the combined resistance of three conductors in parallel when their respective resistances are 24 ohms, 28 ohms, and 33 ohms. The conductance of the first conductor then is $\frac{1}{24}$, or 0.04166, ampere; the

conductance of the second conductor is $\frac{1}{28}$, or 0.03571, ampere; the conductance of the third conductor is $\frac{1}{33}$, or 0.03030, ampere; the sum of the conductances is 0.10767 ampere. Substituting 1 volt for volts and 0.10767 ampere for amperes in the equation,

Resistance = $\frac{\text{volts}}{\text{amperes}}$, we have Resistance = $\frac{1}{0.10767}$ or 9.287 ohms.

Expressing algebraically our computation of the combined resistances of conductors in a parallel circuit, we may use the following equation, $\frac{1}{R_x} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$, in which R_x represents the total resistance and R_1 , R_2 , and R_3 represent resistances of the separate conductors.

To summarize from the foregoing, we have gathered the following information about a parallel circuit: (1) the voltage is the same in each branch of the circuit; (2) the total current is the

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sum of the currents flowing through the branches; and (3) the total resistance is less than the resistance of the smallest branch.

ANSWER THESE QUESTIONS

1. How is resistance measured by the voltmeter-ammeter method?
2. How is resistance measured by the Wheatstone bridge? How is the Wheatstone bridge used to measure temperature in aviation? How is it used to determine the fuel-air ratio?
3. What is the law of length as applied to resistance? How may the law be expressed algebraically?
4. What is the law of size? How is the cross section of conductors commonly indicated?
5. What is meant by resistivity, or specific resistance? What substances have relatively low resistivity?
6. How does temperature affect the resistance of a conductor? What is meant by the temperature coefficient of resistance?
7. How may one law of resistance be derived from several laws?
8. What is meant by a series circuit? What facts are most important about a series circuit?
9. What is meant by a parallel circuit? What facts are most important about a parallel circuit?
10. How is resistance determined in a series circuit? in a parallel circuit?

SOLVE THESE PROBLEMS

A

1. What is the resistance of a coil of wire in which a current of 10 amperes is flowing on a 110-volt line?
2. If a copper wire 1000 ft. long has a resistance of 16 ohms, what is the resistance of 25 ft. of this wire?
3. If the resistance of a copper wire 100 ft. long whose diameter is 20 mils is 2.56 ohms, what is the resistance of a copper wire 100 ft. long whose diameter is 50 mils?
4. If the resistance of 1000 ft. of aluminum wire is 6.8 ohms when the temperature is 20°C ., what is the resistance of the same wire when the temperature is $100^{\circ}\text{Centigrade}$? The temperature coefficient is 0.004 ohm per ohm per degree.
5. Find the resistance of 30 ft. of nichrome wire whose diameter is 0.032 inch. The resistance constant is 660 ohms per mil-foot.

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B

6. Find the combined resistance in parallel of 6 lamps if the resistance of each lamp is 360 ohms.
7. Find the total resistance of a motor whose resistance is 10 ohms, a lamp whose resistance is 120 ohms, and an electromagnet whose resistance is 8 ohms when they are connected in series.
8. Find the combined resistance when the motor, lamp, and electromagnet of problem 7 are connected in parallel.
9. How much current will flow through the motor, lamp, and electromagnet in problem 7 if the total voltage is 115 volts? What is the P.D. across each?
10. How much current will flow in a circuit in problem 8 if the total voltage is 115 volts? What is the voltage across each? What is the current through each?

AREA THREE

How Can a Direct Current Be Produced by Chemical Action?

We have already learned that an electric current flows along a conductor in much the same manner as water flows through a pipe. Let us carry the comparison further to understand why an electric current flows. Water flows through pipes because of pressure exerted somewhere in the system. Electricity flows through a circuit because of pressure exerted somewhere in the circuit.

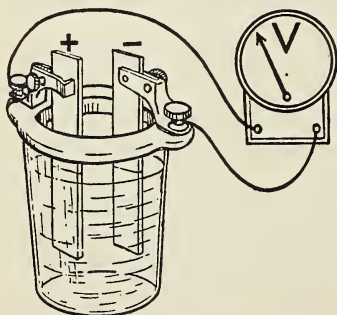


Fig. 228. Diagram of simple cell connected to a voltmeter.

How chemical action produces electrical pressure. Electrical pressure, or e.m.f., may be produced in a circuit either by a generator or by a device in which electricity is produced by chemical action, as in a simple cell, frequently known as a voltaic cell, after the name of its inventor, Count Alessandro Volta. We may make a simple cell, as shown in Figure 228, by filling a glass

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tumbler nearly full of water and adding a little sulfuric acid. On top of the tumbler we place a porcelain cap to which are attached two clamps, one holding a strip of zinc and the other a strip of copper. Finally we connect the clamps to a low-reading voltmeter and find that the copper plate is charged positively and the zinc plate is charged negatively. In order to understand what causes the charge, let us consider three topics as follows: (1) how ionization takes place; (2) how the zinc gets a negative charge; (3) how the copper gets a positive charge.

How ionization takes place. When a solution is formed of a mixture of sulfuric acid and water, ionization takes place in the solution. This means that some of the sulfuric-acid molecules, represented by the formula H_2SO_4 , break up into three electrically charged particles, or ions, two H ions and one SO_4 ion. In this change each H ion loses one electron to the SO_4 ion. As a result it carries a positive charge and the SO_4 a negative charge. A solution that contains charged ions is known as an electrolyte or electrolytic solution and is a conductor of electricity. Distilled water and such solutions as sugar dissolved in water are not electrolytes because they do not ionize.

How the zinc gets a negative charge. If in the cell described the zinc plate and the copper plate are connected externally by a low-resistance conductor for some time, we can see that the zinc plate is being dissolved. The zinc ions have left the plate and have combined with the SO_4 ions in the solution to form an entirely different substance known as zinc sulfate. Since the SO_4 ion is negatively charged, the ions of zinc that unite with it are positively charged. A positively charged atom must have lost electrons, and therefore every atom of zinc that leaves the plate lacks electrons. The lost electrons have been left behind on the plate and, since the plate has too many electrons, it becomes negatively charged. So the zinc plate gets its negative charge because it is dissolved. We always find this to be true in cells: *The dissolved plate is negative.*

How the copper plate gets a positive charge. As we have seen, in the electrolyte of the cell we have free positively charged

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H ions. We may wonder why the positively charged H ions do not go to the negatively charged zinc plate, since unlike charges attract each other. The reason is that the zinc ions that leave the zinc plate to go into combination with the SO_4 ions are charged positively; and these positively charged zinc ions form a positively charged screen around the zinc plate, a screen which repels the hydrogen ions and drives them away. The hydrogen ions, however, reach the copper plate; and, since they lack electrons, they take them away from the copper, leaving it with a lack of electrons, or positively charged. In this way the copper plate gets its positive charge. When the hydrogen ions get the electrons they lack, they become neutral atoms and unite with other neutral hydrogen atoms to form bubbles of hydrogen gas. Hydrogen ions do not unite with each other to form bubbles because like charges repel each other. Only at the positive plate of a cell are bubbles of hydrogen gas formed.

Materials used and e.m.f. If the plates of the simple cell are connected to a low-reading voltmeter, a potential difference of one volt is seen to exist between the zinc and the copper. If a carbon plate is substituted for copper, the P.D. is greater. If the plate used with the zinc is lead instead of copper, the P.D. is less. Thus it can be shown that, when the plates are changed, there is a change in the P.D. between the plates of the cell. Therefore, we may say that *the e.m.f. of a cell depends upon the material of which the plates are made.*

One may put the zinc and copper electrodes into different electrolytes, such as a solution of water, different acids, bases, or salts, and a different e.m.f. will be obtained in each case. The e.m.f. depends on the kind of electrolyte used. Therefore we may say that *the e.m.f. of a cell depends upon the materials of which the electrolyte is composed.*

Defects of the simple cell. If a large current is taken from a simple cell for a short time, it will be found that polarization takes place. The polarization is caused by an accumulation of hydrogen

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gas bubbles on the positive plate. The effect is to replace the copper surface partially by a hydrogen surface. This not only reduces the e.m.f. of the cell but also increases its resistance. Some cells polarize so rapidly that they can be used only intermittently for such purposes as ringing doorbells. Polarization can be reduced or entirely eliminated if the positive plate is covered with some substance, such as manganese dioxide, that will combine with the hydrogen gas as fast as it forms.

Another defect of the simple cell is local action that is caused by impurities of zinc such as carbon or iron particles. Such particles act like positive poles and set up an electric current between the impurities and the surrounding zinc. This action between the impurities and the zinc wastes the zinc and causes bubbles to form, thus reducing the effectiveness of the cell. Local action can be prevented by amalgamating the zinc with mercury. The zinc atoms dissolve in the mercury, which covers the impurities and prevents them from coming into contact with the solution, and hence local action is prevented.

Size of cell and its e.m.f. We let a cell containing a copper plate and a zinc plate in dilute sulfuric acid be set up as shown in Figure 229, with a voltmeter connected with the plates, and an ammeter, resistance box, and switch in the external circuit. With the switch open, the voltmeter is read. It should register one volt. Let us separate the plates as completely as possible and read the voltmeter. Then let us bring the two plates close together. If the plates are lifted until they are only half in the solution, the size of the plates (in solution) is changed. If a good voltmeter

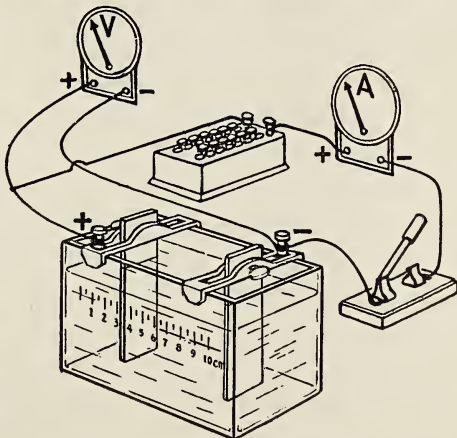


Fig. 229. Apparatus for measuring voltage of a cell while making changes in the plates.

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is used, it can be seen that the voltmeter registers the same whether the plates are far apart or close together, partly submerged or fully submerged. In other words, the size or proximity of the plates does not change the voltage or the e.m.f. of the cell. As an illustration, a small dry cell, such as is used in a flashlight, and an ordinary dry cell have the same voltage.

Size and resistance. Let us close the switch so that a closed circuit is obtained through the ammeter. When the plates are moved far apart, the reading of the ammeter decreases, and when the plates are moved close together, the reading increases. It decreases also when the size of the plates is decreased by lifting them partly out of the solution. Thus, the amount of current delivered by the cell depends on the size of the plates and the distance they are apart. The current in the circuit depends on the two factors e.m.f. and resistance. It was shown on the preceding page that the e.m.f. is not affected by the size and spacing of plates. Therefore it is the resistance of the cell that depends upon the size and spacing of plates. The cell is a conductor just as the external circuit is. Its resistance is affected by length, size, material, and temperature.

How the resistance of cells is found. Using the setup indicated in Figure 229, let us take the open-circuit voltage; that is, read the voltmeter with the switch open. Then let us take the closed-circuit voltage; that is, close the switch and read the voltmeter and the ammeter quickly. (The switch should not be left closed very long because the cell may polarize.) The difference between the open-circuit voltage and the closed-circuit voltage is known as the cell drop. The cell drop, which depends upon the current and the resistance of the cell, is merely the voltage required to send the current through the cell. If the cell drop is divided by the current, the quotient is equal to the resistance of the cell, as indicated in the following equation:

$$R = \frac{E - V}{I}.$$

DIRECT CURRENT BY CHEMICAL ACTION

In this equation, E represents the open-circuit voltage, V represents the closed-circuit, or terminal, voltage, I represents the current, R represents the resistance of the cell. The combination IR represents the cell drop.

Combination of cells. When cells are combined, they may be arranged in either of two ways: (1) in series or (2) in parallel. When cells are arranged in series, they are arranged as shown in the upper drawing in Figure 230, with the negative terminal of one cell connected with the positive terminal of the next cell, and so on. When cells are arranged in parallel, they are arranged as shown in the lower drawing in Figure 230, with all the positive terminals connected and all the negative terminals connected. To see how these arrangements

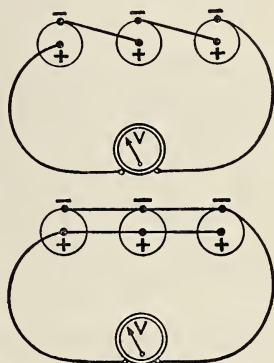


Fig. 230. The upper drawing shows cells in series and the lower drawing cells in parallel.

work, let us examine the two arrangements of pumps shown in Figure 231. In the upper arrangement, which corresponds to the series arrangement of cells, each pump lifts water into the next

higher tank and the three pumps create three times as much difference in level as one pump could create. In the lower arrangement, which corresponds to the parallel arrangement of cells, the three pumps lift the water to no higher level because the pumps are on the same level. Thus the series arrangement builds up the e.m.f. and the parallel arrangement does not. In a series combination of cells, when the cells are of equal strength, the combined e.m.f.

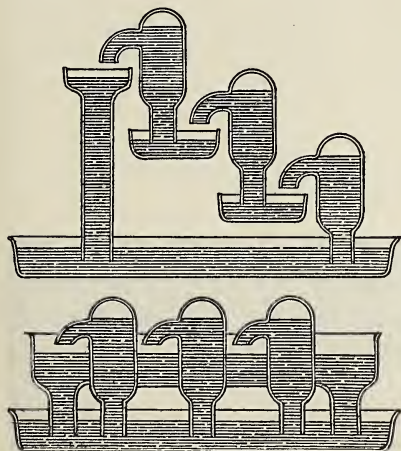


Fig. 231. Diagrams of water pumps operating in series (upper) and in parallel (lower).

PIONEER WORKERS AMONG ELECTRONS

of the cells is equal to the e.m.f. of one cell multiplied by the number of cells. If N represents the number of cells, E the e.m.f. of each cell, R_e the external resistance, and R_i the resistance of each cell, we may apply the equation for Ohm's law as follows:

$$I = \frac{EN}{R_e + R_i N}.$$

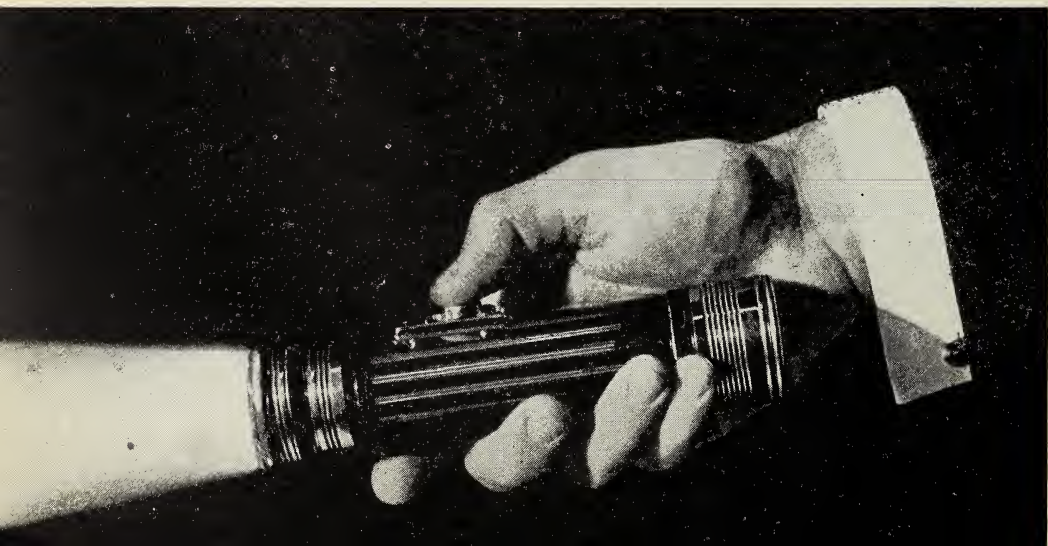
In a parallel combination of cells, the voltmeter registers the same between the positive terminal and the negative terminal of each cell, regardless of how many cells are included. This condition may be explained by the fact that the combination merely increases the size of the plates and does not affect the e.m.f. The resistance of the cells decreases because the resistance is inversely proportional to the size of the plates. The combined resistance of any number N of similar cells in parallel is $\frac{1}{N}$ times the resistance of one cell. The current produced by a combination of similar cells may be expressed in the following equation:

$$I = \frac{E}{R_e + \frac{R_i}{N}}.$$

The dry cell. As we have learned, the value of a cell is determined by (1) the amount of e.m.f. it produces, (2) its resistance, and (3) whether it polarizes or not. Various forms of cells in common use differ chiefly in relation to the above conditions. In

This picture shows a flashlight in use. Dry cells are universally used in flashlights because they are convenient in size and very efficient for intermittent use.

H. Armstrong Roberts



DIRECT CURRENT BY CHEMICAL ACTION

recent years the dry cell has displaced all other types of cells for ringing doorbells, for use in flashlights, and for doing other types of intermittent work. In a dry cell, as shown in Figure 232, the negative plate is the zinc container. The positive plate is a carbon rod that is surrounded by a paste of ammonium chloride (sal ammoniac), carbon granules, manganese dioxide, zinc chloride, and a small quantity of water. The zinc container is lined with

an absorbent layer of blotting paper that is saturated with a water solution of ammonium chloride and zinc chloride. The mixture fills the container to within about one inch of the top. The top is sealed with a pitch composition. The electrolyte is the ammonium chloride. The manganese dioxide is put in to remove the hydrogen from the positive plate, thus acting as a depolarizer. The zinc chloride is put in to overcome the polarization caused by ammonia.

A dry cell produces an e.m.f. of 1.5 volts in an open circuit. Its resistance depends on its size. For the size most commonly used, the resistance is about 0.05 ohm. It polarizes, but the depolarizing agent, manganese dioxide, removes the hydrogen. These cells weaken if used to deliver a strong current for a long time, but they recover their strength on an open circuit. They are popular because they are convenient and because they can deliver 30 amperes or more on a momentary short circuit owing to their low resistance. The life of a dry cell depends partially upon the manner in which it is used. For example, when a dry cell is used continuously over a period of time, its open-circuit voltage decreases and its resistance greatly increases. When a cell is not used continuously, however, its open-circuit voltage decreases less rapidly and its resistance increases less rapidly.

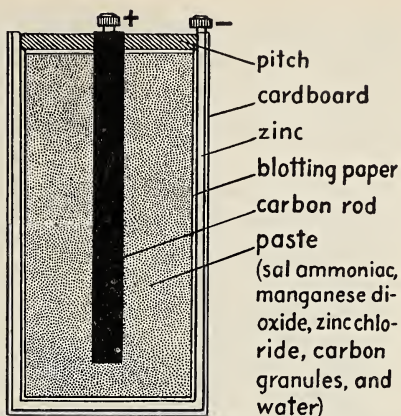


Fig. 232. Cross-section diagram of a dry cell showing the arrangement of essential parts.

PIONEER WORKERS AMONG ELECTRONS

The Weston normal cell. A cell used for testing voltage is the Weston normal cell shown in Figure 233. The positive electrode of this cell consists of mercury over which is a layer of mercurous sulfate. The negative electrode consists of a saturated solution of cadmium amalgam over which is a layer of cadmium sulfate. Over these layers are other chemicals especially suited to the purpose. This cell is noted for its constant voltage and hence has been accepted by international agreement among scientists as a basis for defining the volt. The electromotive force of this cell at a temperature of 20° Centigrade is 1.0183 volts. Therefore a standard volt may be defined

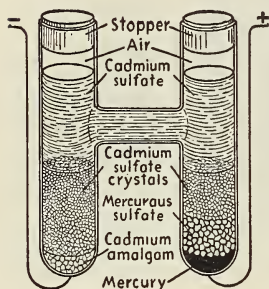


Fig. 233. Cross section showing the parts of the Weston normal cell.

as $\frac{1}{1.0183}$ of the e.m.f. of the Weston cell.

ANSWER THESE QUESTIONS

1. What is meant by ionization in a solution? Do all solutions ionize? Why?
2. How does the negative electrode get its charge?
3. How does the positive electrode get its charge?
4. Why do hydrogen bubbles not appear at the surface when water and sulfuric acid are mixed?
5. What determines the e.m.f. of a cell?
6. Why do bubbles appear at the zinc electrode? How can this defect be overcome?
7. Why do the bubbles at the positive electrode reduce the effectiveness of the cell? How can this defect be avoided?
8. What conditions determine the e.m.f. of a cell? What determines the resistance of a cell?
9. How can the resistance of a cell be found experimentally?
10. Why is the terminal voltage of a cell always less when delivering a current than when on open circuit?
11. What is the effect of connecting cells in series on (1) their combined e.m.f.? (2) their combined resistance?
12. What determines the most effective combination of cells?
13. How is the standard volt defined?

LIQUID CONDUCTORS

SOLVE THESE PROBLEMS

A

1. A dry cell has an open-circuit voltage of 1.5 volts. When delivering a current of 10 amperes, the terminal voltage reads 1 volt. What is the internal resistance of the cell?

2. Four dry cells connected in series show an open-circuit voltage of 6 volts. On a closed circuit through an ammeter and variable resistance, the voltmeter registers 4 volts when the ammeter registers 10 amperes. Find the combined internal resistance of the cells.

3. Each of six dry cells has an e.m.f. of 1.5 volts and an internal resistance of 0.05 ohm. How much current can the dry cells send through a coil of 4 ohms (a) when the cells are in series? (b) when they are in parallel?

4. A dry cell produces a current of 15 amperes when connected to an ammeter that has a resistance of 0.05 ohm. Find the resistance of the cell.

B

5. Three cells have an internal resistance of 0.05, 0.08, and 1.2 ohms, respectively. What is their combined resistance (a) when connected in series? (b) when connected in parallel?

6. Two dry cells whose e.m.f. is 1.5 volts each, when connected in series, will send 3 amperes through a coil whose resistance is 0.8 ohm. Find the resistance of each cell.

7. In a storage-battery lighting system using a 32-volt battery of 0.5 ohm internal resistance, five 20-ohm lamps in parallel are lighted. The connecting wires have a resistance of 1.5 ohms. What is the total resistance of the circuit? How much current is flowing through the battery? How much current is flowing in each lamp? What is the terminal voltage of the battery? What is the voltage across each lamp?

AREA FOUR

What Effects Are Produced When a Direct Current of Electricity Passes through a Liquid Conductor?

Throughout the first three areas of this unit we have made comparisons between currents of electricity and currents of water in discussing such topics as resistance and pressure. We have

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described the flow of electric current through the wires of a circuit and compared it with the flow of water through the pipes of a water system. Now, however, we shall describe how water itself or other liquids may be used to conduct electricity. When we understand how solutions act as conductors, we can understand also the basic facts about electrolysis, electroplating, and the construction and operation of storage batteries.

Liquids as conductors. Let us set up apparatus with copper plates similar to that shown in Figure 234 and test various liquids to see whether they are electrolytes—that is, whether they conduct elec-

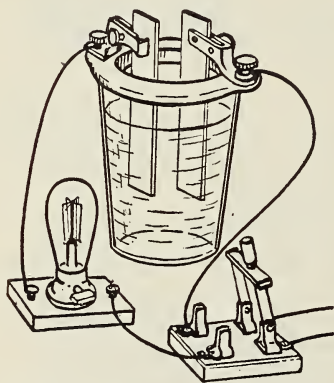


Fig. 234. Experiment with conductivity of different solutions.

tricity. The test of conductivity in each case will be whether the lamp lights when the switch is closed. First we place distilled water in the glass jar and close the switch, but the lamp does not light, showing that distilled water is not an electrolyte. Next we dissolve sugar in the water, thus securing a sugar solution, but still the lamp does not light. Finally we place water in the glass jar and add a few drops of acid, forming an acid solution. In this case the lamp lights, showing that the acid solution is an

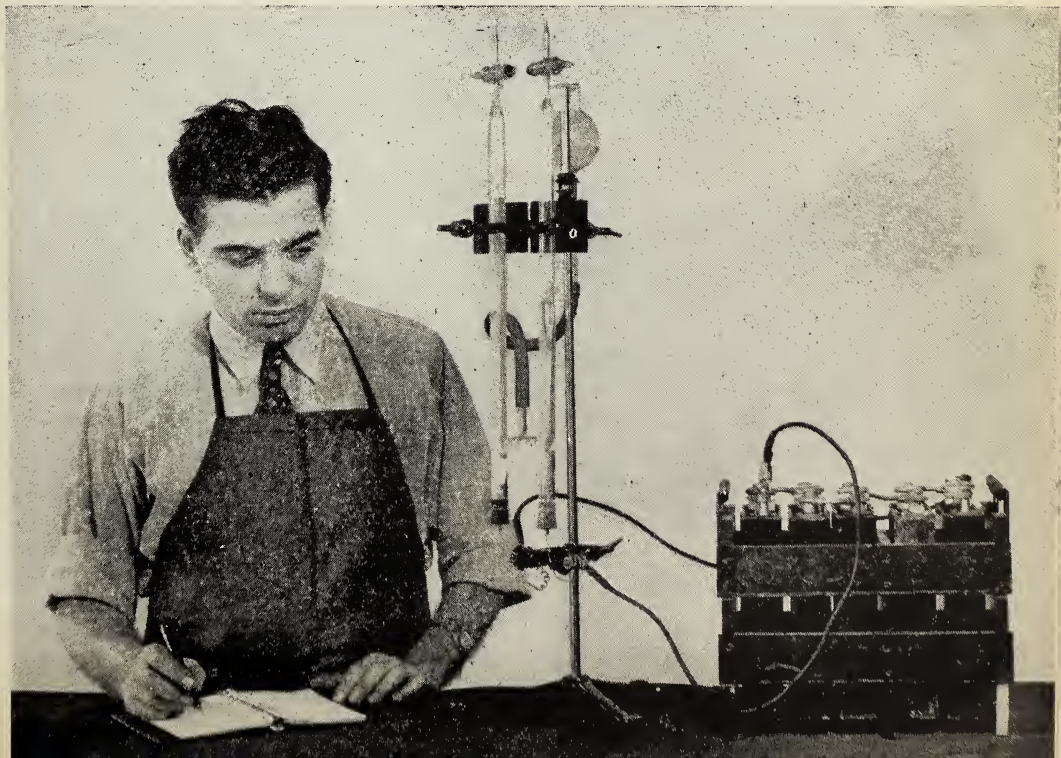
electrolyte. Should we carry the experiment far enough, we should find that solutions made up of water and acids, bases, or salts are electrolytes.

An experiment in electrolysis. Now let us perform an experiment with an electrolysis tube to determine what happens when an electric current passes through an electrolyte. An electrolysis tube is somewhat like the letter **H** with the arms sealed at the top and closed with rubber stoppers at the bottom. We place water in the tubes, add a little sulfuric acid, and then place platinum electrodes through the rubber stoppers and connect these

LIQUID CONDUCTORS

electrodes with the cells of a battery arranged in series. The electrode that we connect with the positive terminal of the battery we may call the anode, and the electrode that we connect with the negative terminal, the cathode. When we connect the apparatus, bubbles begin to rise in the arms of the electrolysis tube, indicating that a current is flowing through the liquid. Soon we observe that bubbles form twice as fast at the cathode as at the anode. After a few minutes we disconnect one of the wires to the battery and test the gases that have collected over the liquid in each arm. When we open the stopcock of the right-hand arm and apply a match to the escaping gas, we find that it burns with a pale-blue flame, indicating that it is hydrogen. When we open the stopcock of the left-hand arm and hold a glowing stick in the escaping gas, it bursts into a flame, indicating that the gas is oxygen. Thus we find that the electric current has decomposed the water of the solution into two gases, hydrogen and oxygen. The decomposition of a liquid when an electric current is passed through it is known as electrolysis.

This student is conducting an experiment with the aid of electrolysis. He is making observations as the electrolytic process separates the water into its elements. In the center of the picture is an electrolysis tube, in which the solution is decomposed.



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Analysis by electrolysis. In a solution of water and sulfuric acid, we have a certain number of free $H^+ H^+$ ions and SO_4^{--} ions, as was explained previously. When the platinum plates were charged positively and negatively by being connected to the positive and negative electrodes of the battery, the SO_4^{--} ions were attracted to the positively charged platinum electrode and there gave up the extra electrons. The SO_4 particles then reacted with water, H_2O , forming H_2SO_4 , and released oxygen, O , which appeared as bubbles at the positive electrode. The $H^+ H^+$ ions were attracted to the negative electrode and were neutralized by taking electrons from the electrode. The neutralized hydrogen atoms appeared in bubbles at the negative electrode.

We can see that the current of electricity passes through the liquid by the migration of ions in the liquid to the positive and negative electrodes. For each H_2SO_4 molecule that breaks up or dissociates into ions of $H^+ H^+$ and SO_4^{--} , another molecule of H_2SO_4 is formed, so that the total number of H_2SO_4 molecules in the solution remains the same. A molecule of water, H_2O , however, breaks up into two atoms of hydrogen and one of oxygen. This process is called the electrolysis of water.

Electroplating. Electroplating is an application of electrolysis. The method of electroplating is illustrated by a simple experiment. In Figure 235, *A* is a plate of copper and *B* a strip of carbon or lead. Let us pour a solution of copper sulfate into the vessel.

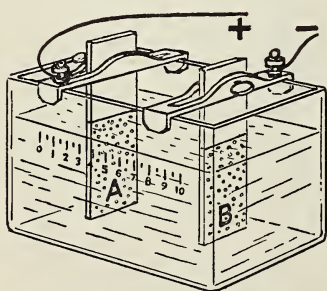


Fig. 235. Apparatus arranged for experiment with electroplating.

Then we connect *A* to the positive terminal of a battery and *B* to the negative terminal. The battery may consist of two or more dry cells or of a storage battery. In a short time we shall see that *B* has received a coating of copper. The copper ions, Cu^{++} , which are positive, go to the negative plate *B* and are deposited upon this. The SO_4^{--} ions, which are negative, go to the positive electrode *A*. Atoms

of copper leave the copper plate as positive charged copper ions. The copper plate is dissolved as fast as the copper ions are deposited on the negative electrode, and therefore the strength of the solution is kept constant.

In plating with any metal the anode, or positive electrode, is that metal, and the article to be plated must be the cathode, or the negative electrode. This process is used to coat many metal articles, that corrode in air, with nickel or chromium, which do not corrode. Much cheap jewelry is plated with gold or silver by this process.

Chromium plating. Chromium plating, which has been extensively used on automobiles until very recently, differs from all other kinds of plating. The anode is not chromium but lead. The chromium that is deposited is obtained from the electrolyte, which is a compound of chromium, chromic acid, or chromium trioxide. Lead does not go from the anode into the solution, but oxygen appears at the anode as in electrolysis. As chromium will not adhere to steel, the article must first be plated with copper. Because chromium is very hard—much harder than steel—it resists corrosion by alkalis and acids and takes a high polish.

Electrotyping. Electrotyping is a form of electroplating used in the printing of books. Most books that are made in large quantities are printed from electrotype plates. As the first step in the process a page is set up in the form of common type. Then a mold is made of this in wax or gutta-percha. The mold is covered with graphite to make it a conductor, as wax is a nonconductor. The graphite-covered mold is then placed in a solution of copper sulfate and attached to the negative electrode, so that it becomes the cathode. A copper plate acts as the anode. When a sheet of copper with the thickness of a visiting card has been deposited on the mold, the mold is removed from the solution. The wax is then replaced by a type-metal backing for the copper plate, which gives the new mold the strength necessary to withstand the constant pressure exerted on it in the printing process.



Michael Faraday
(1791-1867)

Michael Faraday was the son of a London blacksmith. His curiosity and determination to learn took the place of a formal education. His important scientific researches and discoveries are numerous. He formulated the laws governing electrolysis and experimented extensively with magnetism. His most important contribution to science was the discovery of electromagnetic induction.

Ewing Galloway

Refining of metals. When copper comes from the smelting works, it is not pure enough for some uses. For example, in this state it cannot be used as an electrical conductor. Therefore copper is refined by the electrolytic process. In this process the crude copper is the anode and a sheet of pure copper is the cathode. As the crude copper anode is dissolved, pure copper is deposited on the cathode, and the impurities sink to the bottom of the vessel. Other important products of the electrochemical process are aluminum, carborundum, graphite, soda lye, chlorine, and nitrogen compounds used in making fertilizers and explosives.

Faraday's laws of electrolysis. In 1834 Michael Faraday discovered the fundamental facts about electrolysis. These facts may be summed up as a law stated thus: *The mass of any substance carried through a solution is proportional to the product of the current and the time it is allowed to flow.* This may be expressed symbolically as $M = KIt$, where M is the mass in grams appearing at the cathode, I is the current in amperes, and t is the time in seconds. K is a constant depending only on what substance is being carried to the cathode, and is called the electrochemical equivalent or grams of substance deposited per ampere second. The electrochemical equivalents of a few common substances are given in the table on the following page.

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Aluminum.....	0.0000939	gram per ampere second
Chromium.....	0.0001796	gram per ampere second
Copper.....	0.0003294	gram per ampere second
Gold.....	0.0006812	gram per ampere second
Hydrogen.....	0.00001045	gram per ampere second
Nickel.....	0.000304	gram per ampere second
Oxygen.....	0.00008291	gram per ampere second
Silver.....	0.001118	gram per ampere second

Legal definitions of units. The legal unit of a quantity of electricity is known as the coulomb. The coulomb, which is derived from the field of electroplating, is defined legally as “the quantity of electricity required to deposit 0.001118 gram of silver.” Expressed in another form, it is the quantity of electricity moved by a current of one ampere flowing for one second. The ampere is defined legally as “the quantity of current that deposits 0.001118 gram of silver in one second.” What definition of an ampere has been given earlier in the unit?

HOW ELECTRICAL ENERGY IS CHANGED TO CHEMICAL ENERGY

Storage batteries. Let us assemble apparatus for charging and discharging a cell, as shown in Figure 236, using two lead plates in the cell. Fill the cell nearly full of a solution of sulfuric acid and distilled water, using one part of acid to two parts of water.

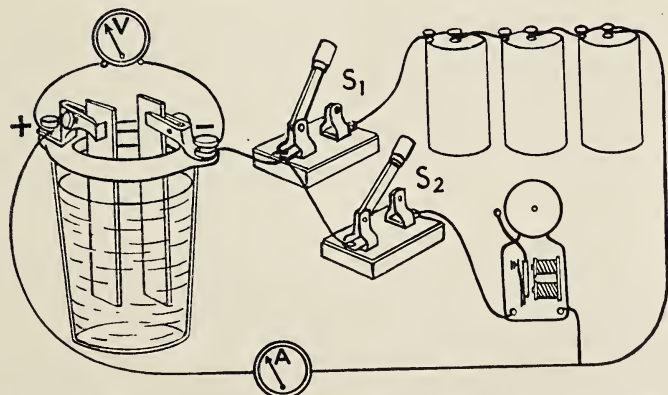


Fig. 236. Arrangement of apparatus for experiment with storage battery.

PIONEER WORKERS AMONG ELECTRONS

Chemical action occurs between the sulfuric acid, H_2SO_4 , and the lead, Pb, a minute amount of lead sulfate, PbSO_4 , forming on the surface of both plates. Leave both switches open and observe that the voltmeter shows no reading. Close switch S_1 and observe by the ammeter that a current flows through the circuit. The current passing through the sulfuric-acid solution causes the lead sulfate, PbSO_4 , on the negative plate, or cathode, to be reduced to grayish metallic lead, Pb. On the positive plate, or anode, the current causes the lead sulfate, PbSO_4 , to be oxidized into reddish-brown lead peroxide, PbO_2 . If we allow the current to flow for a few minutes and then open the switch, we find that the reading of the voltmeter is about 2 volts. This reading represents the potential difference between lead peroxide, PbO_2 , and lead, Pb, in the sulfuric acid, H_2SO_4 . If we close switch S_2 , a current flows through the circuit containing the electric bell and causes the bell to ring. According to the direction of deflection of the ammeter, the current flows in the opposite direction from before. In the first situation, that is, when switch S_1 is closed, the cell is charged, and in the latter situation, when switch S_2 is closed, the cell is discharged. When the cell is charged the following chemical action occurs: $2\text{PbSO}_4 + 2\text{H}_2\text{O} \rightarrow \text{PbO}_2 + \text{Pb} + 2\text{H}_2\text{SO}_4$. When the cell is discharged, the chemical action is reversed, namely: $\text{PbO}_2 + \text{Pb} + 2\text{H}_2\text{SO}_4 \rightarrow 2\text{PbSO}_4 + 2\text{H}_2\text{O}$.

What is stored. When the cell is charged, it, like the simple cell, has two dissimilar plates in an electrolyte. When discharging, the red plate is the positive electrode and the gray plate is the negative electrode. The current produced by the cell flows through the cell in a direction opposite to the direction of the charging current. In charging, as has been shown, the H_2O molecule is broken up and H_2SO_4 molecules are formed. Therefore the concentration of the sulfuric acid increases while the cell is being charged. The storage cell does not store up electricity; it stores up chemical energy.

The energy of the electric current, which is charging it, is converted into potential energy by the reduction of the negative

electrode and the oxidation of the positive electrode. When the cell is being discharged, the chemical energy is being converted into electrical energy.

The commercial storage battery. The commercial battery operates on the same principle as a simple storage cell, but it is more efficient because each electrode consists of a set of specially prepared plates. These plates are made in the form of a grid rather than solid, as shown in Figure 237. The material used is an alloy of lead and antimony, the antimony being added to provide strength. The grids of the positive plate are filled with a paste of red oxide, and the grids of the negative plate with a paste of lead monoxide, or litharge. Separating the grids are thin sheets of rubber or wood that prevent the grids from touching one another. The grids are usually arranged in three cells, the cells in turn being connected in series. The electrolyte is the same as in the lead storage cell already described; namely, a solution of sulfuric acid. The complete battery is incased in a rectangular box made of composition materials that resist the action of chemicals. Such a battery is the type commonly used in automobiles for starting, lighting, and ignition purposes. A 3-cell battery of this type produces an e.m.f. of 6 volts, and a 6-cell battery produces an e.m.f. of 12 volts. Since the plates are numerous, large, and close together, the resistance of the battery is relatively low.

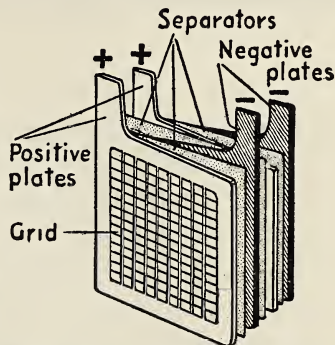


Fig. 237. Drawing showing essential parts of a storage-battery cell.

The Edison storage battery. Another battery that is widely used is the Edison storage battery, named after its inventor, Thomas A. Edison. This battery differs greatly from the lead storage battery because of the materials used in construction and the design of the electrodes. Each plate of the positive electrode consists



Thomas Alva Edison

(1847-1931)

Thomas Edison was one of the geniuses of American science. He had very little formal education. His natural curiosity and love of experimenting led to discoveries that have greatly changed our ways of living. Among Edison's most remarkable contributions to science are the invention of the incandescent lamp and the phonograph, and certain improvements of telephone and telegraph instruments.

Century Photos, Inc.

of nickel-plated perforated tubes filled with nickel hydroxide and nickel flakes, and each plate of the negative electrode consists of nickel-plated steel pockets filled with iron oxide. The electrolyte is either potassium hydroxide or sodium hydroxide, one being about as efficient as the other. When the battery charges, the nickel hydroxide of the positive electrode changes to nickel peroxide, and the iron oxide of the negative electrode changes to iron. No apparent change occurs in the electrolyte; oxygen simply passes from the negative electrode to the positive. When the battery discharges, the conditions are reversed; nickel peroxide changes to nickel hydroxide at the positive electrode and iron changes to iron oxide at the negative electrode. Again there is no apparent change in the electrolyte; oxygen simply passes from the positive electrode to the negative. This battery, like the commercial lead battery, is incased in a rectangular case made of composition materials that resist the action of chemicals. On the whole it is very sturdy and compact and occupies relatively little space. When fully charged, it has an e.m.f. of 1.2 volts, but since the electrolyte remains unchanged it cannot be tested with a hydrometer. It has a rather high resistance and hence produces a relatively low momentary force. What advantages does this storage battery have over the commercial lead-cell battery? What disadvantages does it have?

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The care of a storage battery. Under this topic we shall consider only the care of the ordinary commercial lead storage battery, since this is the type commonly used in automobiles, trucks, and the like. When such a battery works—that is, produces a current—the lead peroxide on the positive plate and the litharge on the negative plate combine with the sulfuric acid to form lead sulfate. Through this action the sulfuric acid becomes weaker, the plates become coated more and more with lead sulfate, and the battery generates less electricity. Finally the sulfuric acid is almost completely exhausted, and the e.m.f. of the battery becomes very low.

Ordinarily a storage battery will last two or three years, but a user can do many things to prolong its life. For one thing, he should fill the battery frequently with distilled water in order to keep the solution above the plates. The weaker the solution, the less chemical action takes place and the less rapidly the sulfuric acid is used up. For a second thing, he should have the battery tested frequently to make sure that it is well charged. A hydrometer reading of 1.29 indicates that there is plenty of sulfuric acid in the solution and that the e.m.f. is relatively high.

A reading of 1.20, on the other hand, indicates that the sulfuric acid is greatly reduced and the e.m.f. is low. In the latter case the battery should be charged by the introduction of current in the opposite direction from that being generated in the battery. Such a current reverses the chemical processes taking place in the battery. In other words, it causes lead peroxide to form at the positive plate, lead monoxide, or litharge, to form at the negative plate, and sulfuric acid to form in the electrolyte.

The boy in this picture is examining the structure of a commercial storage battery.



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Rating of storage batteries. The rating of storage batteries is generally based on the eight-hour rate of discharge. A battery is given the rating of 80 ampere-hours if it delivers a current of 10 amperes for eight hours. An ampere-hour represents the capacity of a battery to deliver one ampere for one hour. The normal discharging rate of such a battery would be 10 amperes. Though the battery is capable of delivering 10 amperes for eight hours, it will not deliver 16 amperes for five hours or 80 amperes for one hour. The capacity at higher rates of discharge is controlled by the capacity of the free solution to penetrate the pores of the active material. However, batteries have the capacity to discharge at a very high rate for a very short time. For example, a starting battery with an 80 ampere-hour rating is often momentarily called upon to supply 150 amperes and perhaps more in starting an automobile.

ANSWER THESE QUESTIONS

1. How do liquids conduct electricity?
2. What happens when a current of electricity is sent through a solution of acid and water if platinum electrodes are used?
3. What happens when a current of electricity is sent through a solution of sulfuric acid and water if lead electrodes are used?
4. What did Faraday find out about electrolysis, and what is meant by electrochemical equivalent?
5. How is a commercial storage battery made? Why is this battery more efficient than a simple lead cell?
6. How is an Edison storage battery made? What are its advantages and disadvantages when compared with a lead-acid battery?
7. How can the resistance of the storage battery in an automobile be found?
8. How does a filling-station attendant test the amount of charge in a storage battery?
9. Why should distilled water rather than acid be added to the storage battery in an automobile?
10. How is it possible to get more than 200 amperes from a 6-volt storage battery?
11. Why must the charging voltage of a 6-volt storage battery be greater than 6 volts?

MEANING OF ELECTRIC POWER

SOLVE THESE PROBLEMS

A

1. How much silver will be deposited in 1 hr. from a silver-nitrate solution by 10 amperes of current?
2. How much copper will be deposited from a solution of copper salt in 10 min. by a 30-ampere current?
3. How long will it take to deposit 50 g. of gold by a 20-ampere current?
4. How many amperes of current will be required to collect 1 g. of hydrogen from a solution of sulfuric acid in 1 hour?

B

5. In charging a lead-acid storage battery of 3 cells, the rate of flow of the current through the battery is 10 amperes and the impressed voltage is 6.45 volts. If the internal resistance of each cell is 0.005 ohm, to what voltage will each cell of the battery be raised?
6. Two small lamps, each having a resistance of 4 ohms, are connected in parallel to the terminals of a storage battery whose resistance is 0.5 ohm. What is the total resistance of the circuit? How much current is flowing in the circuit if the e.m.f. of the battery is 6 volts? What is the current in the battery? What is the current through each lamp? What is the terminal voltage of the battery?
7. An iron casting is to be copper-plated and then nickel-plated. The current is to be 8 amperes in each case. How long must it be in each vat to have 397 gr. of each metal deposited on it?

AREA FIVE

What Is Meant by Electric Power?

In many instances in our study of physics thus far we have considered the transfer of energy from one form to another. Especially have we considered the transfer of energy to forms for doing work. In this area we shall consider another phase of transfer; namely, the relation between electrical energy and power.

Power the rate at which energy is used. Whenever an electric current is introduced in a circuit, as we have learned, a potential difference arises, causing electrons to flow from points of higher

PIONEER WORKERS AMONG ELECTRONS

potential to points of lower potential. When electrons move along a conductor, they always expend energy that reappears in some form of reaction. For one thing, they meet resistance caused by friction; consequently they expend energy that appears in the form of heat in the conductor. In some instances they expend energy in chemical activity, as in charging a battery. In other instances they expend energy in mechanical activity, as in running a motor. When electricity expends energy in any mechanical activity, it is said to exert power. Power in this instance means the same as power from any other source. In other words, power means the rate at which energy is used or the amount of energy used within a given time.

How electric power is calculated. If we were to determine the energy that water exerts upon a water wheel, we should multiply the quantity of water that passes through it by the distance through which the water falls. Similarly, in order to find the

The old type of water wheel illustrated in this picture is very convenient for supplying a small unit of power. Many such wheels are still in use on farms and country estates.

H. Armstrong Roberts



MEANING OF ELECTRIC POWER

energy expended by an electric current, we multiply the quantity of electricity (coulombs) by the fall in potential (volts) between the ends of the conductor. The absolute unit of energy is the joule, which is used as the unit of electrical energy.

$$\text{Joules} = \text{volts} \times \text{coulombs}.$$

The instrument most generally used for measuring an electric current, as already explained, is the ammeter. This instrument, however, measures only the rate of flow, or the quantity of electricity passing per second, and hence does not measure the total quantity of electricity. If we multiply the quantity of electricity flowing per second (ampere) by the fall in potential or potential difference (volts), we obtain the power. The unit of power in the field of electricity is the watt, which is an absolute unit.

$$\text{Power in watts} = \text{volts} \times \text{amperes, or}$$

$$\text{Watts} = E \times I.$$

$$\text{Since } E = IR,$$

$$\text{Watts} = I^2 R.$$

$$\text{One thousand watts} = \text{one kilowatt}.$$

$$746 \text{ watts} = \text{one horsepower}.$$

Since electric power is expressed in watts and since a watt is the amount of electrical energy expended in one second, we may find the total energy used in any given time by multiplying the power (watts) by the time expressed in seconds. The result is expressed in joules, or watt-seconds as follows:

$$\text{Energy in joules} = \text{volts} \times \text{amperes} \times \text{time, or}$$

$$\text{Joules} = EIt.$$

$$\text{Joules} = I^2 Rt.$$

Electric-power companies charge for the amount of electrical energy used on the basis of the number of kilowatt-hours used in a month. We find the total amount of electrical energy used, when expressed in kilowatt-hours, by multiplying volts by amperes by time in hours, and dividing the product by 1000. Expressed algebraically:

$$\frac{E \times I \times \text{hours}}{1000} = \text{kilowatt-hours}.$$

PIONEER WORKERS AMONG ELECTRONS

In the case of direct current a voltmeter and an ammeter are used together in determining the electric power. The voltmeter measures the potential difference across the electrical device, and the ammeter measures the rate of flow. To find the power used in a direct-current circuit, we merely multiply the voltmeter reading by the ammeter reading.

$$\text{Watts} = \text{volts} \times \text{amperes, or}$$

$$\text{Watts} = E \times I.$$

To find the total electrical energy used, a watch is needed in addition to the voltmeter and ammeter.

$$\text{Joules} = EIt \text{ (} t = \text{seconds)}, \text{ or}$$

$$\text{Watt-hours} = EIt \text{ (} t = \text{hours)}.$$

In the next unit we shall study an instrument called the wattmeter, in which the voltmeter and ammeter are combined. We shall also study the watt-hour meter in which the time factor is added to the wattmeter.

ANSWER THESE QUESTIONS

1. What is the meaning of power, energy, potential energy, and kinetic energy?
2. How is potential energy produced electrically? How is kinetic energy produced electrically?
3. How can the quantity of electric power being used be determined? In what units is it measured?
4. How can the quantity of electrical energy used within a given time be found? In what units is it measured?
5. What is meant by the kilowatt-hours on an electric-light bill?

SOLVE THESE PROBLEMS

A

1. What power is supplied to a motor that takes 5 amperes from a 115-volt circuit?
2. On the name plate of a motor is marked its average rate of power, given as 5 HP. Change this to kilowatts.
3. The motor of a streetcar takes 10 amperes on a 550-volt circuit. Indicate this power (*a*) in watts; (*b*) in kilowatts; (*c*) in horsepower.

ELECTRICAL ENERGY, HEAT, AND LIGHT

4. Find the cost of running a motor that takes 5 amperes on a 115-volt line for 30 days if it is run on an average of 2 hr. per day at a cost of 5 cents per kilowatt-hour.

5. What is the total quantity of electrical energy in joules used by three 100-watt lamps and five 50-watt lamps for 30 days at an average of 5 hr. per day?

6. What is the power loss on a transmission line whose total resistance is 0.5 ohm when 10 amperes are supplied?

B

7. The specific resistance of copper is 10.4 ohms per mil-foot. If No. 14 copper wire (diameter, 64 mils) is used to transmit power from the powerhouse to a motor, a distance of 1 mi., what would be the power loss of the line when a 10-ampere current is transmitted? What would that cost per hour at 5 cents per kilowatt-hour?

8. A motor takes 6 kw. power and the resistance of the line wires to it is 0.08 ohm each. What is the power lost on the lines (a) for a 110-volt motor? (b) for a 220-volt motor?

9. At 4 cents per kilowatt-hour, how much is the energy worth that is lost in a year of 300 10-hour days in problems 8 (a) and (b)?

AREA SIX

How Is Electrical Energy Changed into Heat Energy or Light Energy?

Already we have learned that when electricity flows through a conductor it expends energy in overcoming resistance and hence generates heat. This process is a very important one in the study of physics, and it is also one that makes a great deal of difference in our way of living. The transformation of electrical energy into heat energy makes it possible for large quantities of intense heat to be generated without eating into our limited fuel supplies. The unlimited supply of electrical energy can be harnessed and used to supply many of our heating needs. In this area we shall study further manifestations of this transfer of energy and discuss some of its practical applications in everyday life.

HEAT ENERGY FROM ELECTRICAL ENERGY

How heat energy is formed. If we place a short piece of wire of high resistance in an electric current, such as the span from A to B in Figure 238, we find that when the switch is closed the wire becomes hot and melts. The melting occurs because the moving

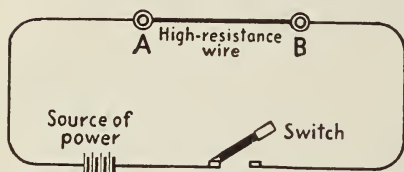


Fig. 238. Arrangement of circuit for showing how electricity creates heat energy.

electrons expend energy in overcoming the resistance of the wire, and therefore transform electrical energy into heat. The heating effect of an electric current accounts for the operation of many practical devices, such as the electric toaster, the electric iron,

the electric percolator, the electric welder, and the electric furnace. An electrical circuit, such as that in the lighting system in an automobile or home, develops very little heat. On the other hand, in such devices as the electric toaster, the electric iron, and the electric furnace certain parts of the circuit develop a great deal of heat. Therefore we may conclude that an electric current always generates heat, in some cases little and in other cases a great deal.

The fuse and the circuit breaker. Frequently when an electrician is seeking the cause of trouble in an electrical circuit, he finds a short circuit, or a place where the wire has become overheated and melted. A short circuit is always very dangerous because the overheated wires are likely to start a fire. The most effective means of offsetting this danger is through the use of a device known as a fuse attached to the circuit. This device contains a lead-alloy wire that melts at a lower temperature than other wires in the circuit and hence prevents the other wires from becoming overheated. If the wiring in a house, for example, is supposed to carry a current of 10 amperes without overheating, the lead-alloy wire is made to melt if the flow becomes greater. Usually the fuse is attached at the point where the house wires join the main circuit.

On streetcars, elevators, and the like, where the current is turned off and on frequently, a device known as a circuit breaker



Ewing Galloway

The young woman in this picture has just poured a cupful of hot coffee from an electric percolator. The electric percolator is one of the many modern conveniences made possible by the transformation of electrical energy into heat energy in controlled quantities.

is used as a protection against overloading. The essential parts of this device are a coil and a soft iron plate. When the current becomes excessive, the coil attracts the plate, causing it to move and release a spring that opens the circuit. To close the circuit again, the operator merely pulls down a handle.

The heat equivalent of electrical energy. Many times in our study of physics we have learned that, when energy changes from one form to another, each unit of the original energy yields a definite quantity of the new energy called the equivalent value. In a change from electrical energy to heat energy, the heat energy is known as the heat equivalent of electrical energy. This equivalent was first determined by Joule, who used an instrument known

as a calorimeter, similar to that shown in Figure 239. Passing electricity through a coil immersed in water, and noting the change in temperature of the water, he found that for each joule of electrical energy used 0.24 heat calorie appeared. Analyzing

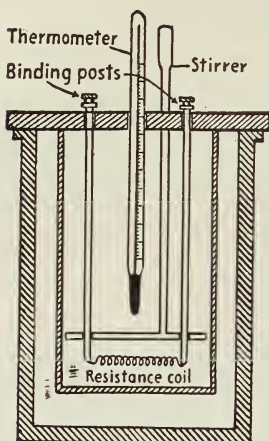


Fig. 239. A calorimeter.

this result in the light of various factors, he developed this law: *The amount of heat generated in a conductor is directly proportional to the resistance, the time, and the square of the current.* If h stands for heat, R for resistance, t for time, and I for the current, we may express the relationship in the form of an equation as follows:

$$h = 0.24I^2Rt.$$

Electric heating devices. Among the many simple electric heating devices are the electric toaster, the electric percolator, the electric waffle iron, the electric flatiron, the electric heating pad, the electric hair drier, and the electric heater. All these devices contain coils of high-resistance wire placed close together so that the heat is concentrated. Such devices are of great help to the housewife, for they cut down the drudgery of work.

Electric heating devices are also widely used in industry, two important devices being the electric welder and the electric furnace. In the use of the electric welder a strong current is passed through the metal pieces to be welded together. This current causes heat to develop at the point of contact and thus to fuse the pieces together. Electric welding is widely used today in repairing streetcar rails and in constructing bridges and the metal framework of buildings. Formerly the metal parts of such structures were joined by riveting, but now they are joined by welding. In the electric furnace, heat is developed in a variety of ways. In some furnaces the heat is generated by a high-resistance coil, and the object to be heated is placed inside the coil. This type of furnace has the capacity to provide a temperature of nearly

2000° Centigrade. Another kind of electric furnace consists of two electrodes which are so arranged that the object to be heated can be attached to them. In this arrangement the object offers resistance directly to the current and thus becomes heated. A somewhat higher temperature is obtained with this arrangement than in the first furnace described. Still another type of electric furnace consists of two carbon rods, the ends of which are brought close together in a refractory crucible, or container designed to withstand great heat. The object to be heated is placed in the crucible. The heat is produced when the current jumps the gap in passing from one carbon rod to the other. Very intense heat, sometimes as great as 3500° Centigrade, can be produced in this type of electric furnace.

The thermocouple, or electric thermometer. We have now considered numerous devices in which an electric current produces heat in a conductor. Now let us consider a device known as a thermocouple in which the reverse is true; namely, in which heat causes an electric current. The thermocouple, shown in Figure 240, consists of a circuit composed partly of iron wire and partly of copper. One end of each wire is attached to an ammeter, and the other ends are twisted together. When heat is applied to the twisted portion, the ammeter shows that an electric current flows in the wire, and indicates the rate of flow in amperes. The more heat applied to the twisted portion, the higher the ammeter reading and the greater the rate of flow. In a commercial thermocouple, such as the pyrometer, used in testing the heat of furnaces, the registering device is calibrated to show degrees of temperature as on a thermometer.

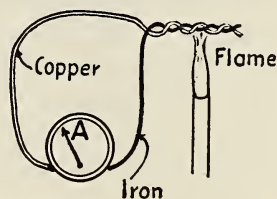
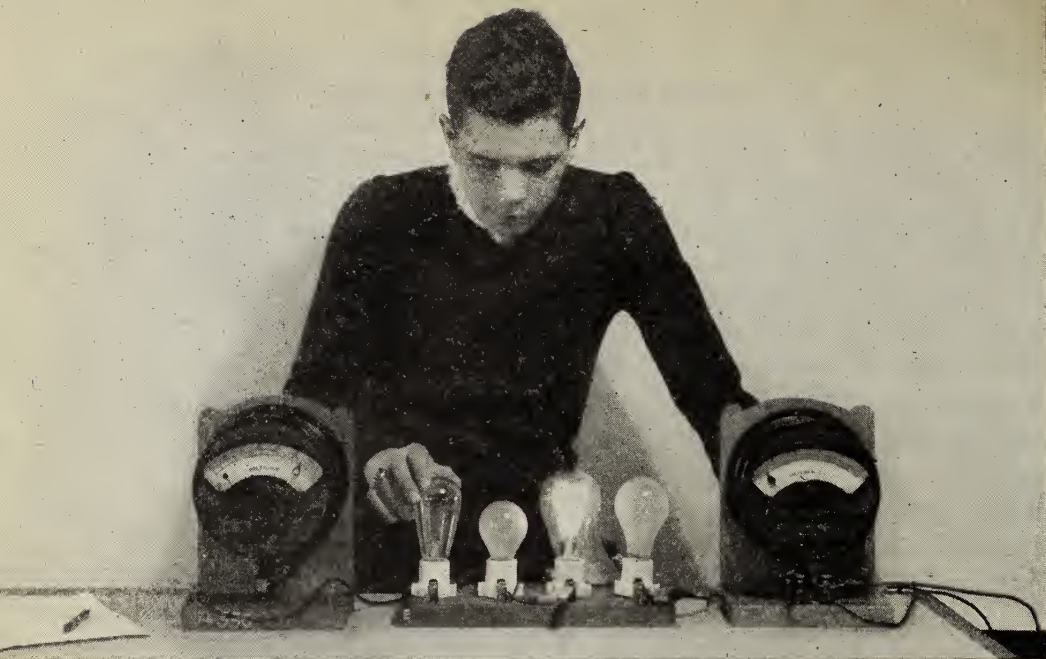


Fig. 240. Essential parts of the electric thermocouple.

The thermocouple is widely used in aviation for determining the temperature of engines on airplanes. In this case the two wires are made of iron and constantan rather than of iron and copper. One end of each wire is attached to a copper ring, and



This student is making observations that will help him to determine the power of various kinds of lamps. He does this by connecting the various lamps to an ammeter-voltmeter circuit and then comparing the readings shown on the two meters.

the other end to a millivoltmeter that registers degrees of temperature. The copper ring is used as a gasket for the spark plug and thus is brought into direct contact with the heat of the cylinder. The heat at the juncture of the constantan and the iron sets up an electromotive force that causes the millivoltmeter to register the temperature.

LIGHT ENERGY FROM ELECTRICAL ENERGY

The incandescent lamp. Under certain conditions when an electric current produces heat in a conductor it also produces light, the light appearing as a result of the heat. The most common form of electric light is the incandescent lamp that was developed by Thomas A. Edison. Since Edison developed this lamp, it has been improved in a variety of ways, but it still operates according to the original principles. Different kinds of materials have been discovered which are now used in the construction of the lamp. Efficient methods have been devised for preventing glare and in

ELECTRICAL ENERGY, HEAT, AND LIGHT

other ways providing for the comfort of its many users. In recent years the manufacture of incandescent lamps has become a large and important industry.

The modern incandescent lamp consists primarily of a filament inclosed in an air-tight glass bulb, as shown in Figure 241. The filament is made of tungsten, a metallic element that offers great resistance to an electric current, has an extremely high melting point, and deteriorates slowly. The filament is wound closely in spirals to concentrate radiation and to reduce the loss of heat by convection. The ends of the filament are supported by two nickel wires, known as lead-in wires, which conduct the current to and from the filament. Other wires made of fine molybdenum wire and known as filament supports help to hold the filament in place.

The glass bulb of the incandescent lamp is filled with a mixture of two gases, nitrogen and argon. These gases are used because they have very little tendency to combine with other elements in their environment. A mica disk is placed above the neck of the bulb to reduce the circulation of gases and thus to prevent overheating in the neck and base of the lamp.

A modern incandescent lamp produces a soft white light that is restful to the eye. Recently glare has been considerably reduced by coating the inside of the bulb with a diffusing enamel known as frost. Lights of different colors are produced by making the bulbs of different colored glass or by coating the bulbs on the inside or outside with different colored enamels. The ordinary lamp has a lifetime of about 750 hours before the filament disintegrates. Its lighting intensity is indicated by its rating in watts; most lamps range in strength from 10 watts to 100 watts.

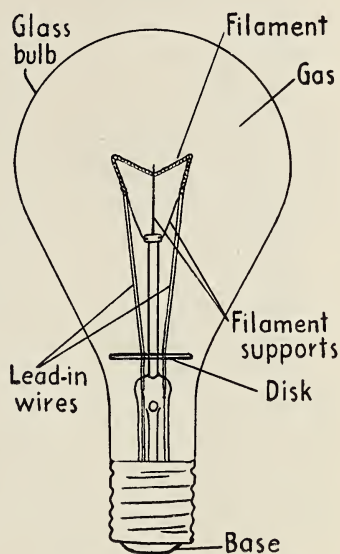


Fig. 241. Diagram of modern incandescent lamp showing essential parts.

PIONEER WORKERS AMONG ELECTRONS

The electric arc lamp. The arc lamp is an older form of lamp than the incandescent lamp; it was invented many years earlier. The arc lamp consists of two carbon rods placed end to end in a straight line or at an angle to each other with a small gap between, as shown in Figure 242. When this lamp is connected with a direct current, the current comes in over one carbon rod and

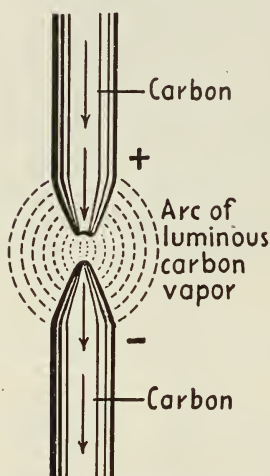


Fig. 242. Diagram showing parts of an arc lamp.

jumps the gap to the other carbon rod. In jumping the gap, the current uses carbon vapor as a conductor. The vapor is formed from the deteriorating end of the rod serving as a positive pole. This vapor, being heated intensely by the passing current, produces a very strong light. The vapor spread between the ends of the rods causes the luminous region to have the shape of an arc, which accounts for the name of the lamp.

The arc lamp is very similar in construction to one form of electric furnace, which we have already considered. The lamp, like the furnace, develops intense heat, often as great as 3500° Centigrade. As the lamp continues in use, a crater forms in the end of the rod used as a positive pole and a cone forms on the end of the rod used as a negative pole. This change in shape on the ends of the rods indicates that carbon passes from the positive pole to the negative pole. The arc light was once widely used in lighting streets, but now is used only in motion-picture machines, searchlights, spotlights, and the like.

The vapor lamp. Another type of lamp is the vapor lamp, which operates on somewhat the same principle as the arc lamp. This lamp produces light from heated vapor, the vapor being heated as the electric current passes from one electrode to the other. The vapor lamp is made in several different forms, one of the most common being the mercury-vapor lamp. The lamp consists of a

ELECTRICAL ENERGY, HEAT, AND LIGHT

vacuum tube two to four feet long with a sealed-in electrode at either end. The tube contains a small quantity of mercury that vaporizes from the heat of the current and emits a brilliant bluish-green light. The light is this color because it is deficient in red rays. The vapor also emits ultraviolet rays, or rays outside the range of vision, and consequently the lamp is especially useful in photographic work.

Another kind of vapor lamp is the sun lamp, which is a modification of the mercury-vapor lamp. In this lamp a quartz bulb is used rather than a glass tube, because the ultraviolet rays pass through quartz more readily than through glass. The electrodes consist of two tungsten projections joined by a fine tungsten filament. The filament causes the mercury to vaporize and form an arc between the two electrodes. The sun lamp is used in health work for its invigorating effects and for killing bacteria. It is called a sun lamp because its rays are the same as the healthful ultraviolet rays that come from the sun.

A third kind of vapor lamp is the sodium-vapor lamp, also called a novalux lamp, which consists of a vacuum tube with sealed-in tungsten electrodes made in the form of coils. This tube is inclosed in a vacuum flask, and inside the tube is a bit of sodium. The electric current causes the sodium to vaporize and form an illuminated arc from one electrode to the other. This lamp is frequently used in lighting highways because it produces excellent illumination, relatively free from glare and shadows.

A fourth kind of vapor lamp is the neon lamp, which consists of electrodes sealed in the ends of vacuum glass tubes bent into any desired shape. The tube is filled with neon, one of the minor elements of the atmosphere. Usually small quantities of other gases are mixed with the neon to achieve different color effects, such as red, blue, and yellow. The neon lamp is used for signs and display advertisements.

The fluorescent lamp. A fourth kind of lamp is the fluorescent lamp, which consists of a vacuum tube a foot and a half to four feet long with a sealed-in electrode at either end, as shown

PIONEER WORKERS AMONG ELECTRONS

in Figure 243. The tube contains a small quantity of mercury that vaporizes and forms a luminous arc between the electrodes. The inner surface of the tube is coated with phosphorescent powder, usually of several different kinds. When the lamp is in operation, the mercury arc radiates ultraviolet rays that cause

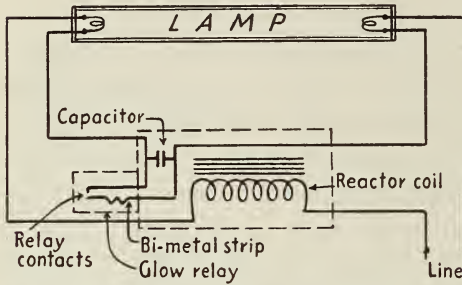


Fig. 243. Cross section of fluorescent lamp apparatus.

the phosphorescent powder to radiate waves within the range of vision. The waves are quite similar to those of ordinary daylight; hence the lamp is very restful to the eyes. Because of this fact the lamp is becoming popular in offices and factories where close work is constantly required.

The phosphorescent powder, as already stated, is usually of different kinds, for a combination is necessary to secure the effects of daylight. By limiting the use of powders or changing the properties of powders, a wide range of colors may be produced. The various powders that are used and the colors that they produce are as follows: calcium tungstate, blue; magnesium tungstate, blue-white; zinc silicate, green; zinc beryllium silicate, yellow-white; and cadmium borate, pink.

The fluorescent lamp does not operate directly and instantly from the regular switch but requires an automatic starting switch known as a glow relay. The relay consists of a bimetal strip attached to an electrode but slightly removed from another electrode. When the circuit is turned on, the first electrode causes this metal strip to expand and make contact with the other electrode, thus closing the circuits to the electrodes in the lamp.

ANSWER THESE QUESTIONS

1. How is heat produced in an electrical circuit?
2. What devices are used as a protection from overheating caused by short circuits?



General Electric Company

Electric lighting has done much to preserve and improve eyesight. The modern lamp that is shown here enables this woman to do fine knitting with a minimum of visual effort.

3. How is the transformation of electrical energy into heat energy used in electrical appliances? What are some of the most common appliances of this kind?

4. What electrical appliances provide heat in industry? How is electric welding done?

5. What is a thermocouple? How is it used in measuring the temperature of a furnace? How is it used in measuring the temperature of an airplane engine?

6. How does an incandescent lamp work? What are the essential parts of the lamp?

7. How does an arc lamp work? Why is the lamp called an arc lamp?

8. What is a vapor lamp? What are some of the forms of vapor lamps? For what purposes is each form used?

9. What is a fluorescent lamp? How does it work? What kind of light does it ordinarily produce? How are different colors obtained? What advantages over other kinds of lamps does it have?

PIONEER WORKERS AMONG ELECTRONS

PROBLEMS TO SOLVE

A

1. A toaster on a 115-volt line takes a 5-ampere current. How many calories of heat does it generate in 10 minutes?
2. An electric iron whose resistance is 20 ohms takes a current of 5 amperes. How much heat will it generate in an hour? What does it cost to run per hour at five cents per kilowatt-hour?
3. How many B.t.u. of heat per hour will be given off by an electric range that takes 10 amperes on a 220-volt circuit if a B.t.u. equals 252 calories?
4. How many calories of heat will be generated per hour by a 100-watt lamp?

B

5. An electric heater is to be designed to generate 1200 B.t.u. per hour. If it is to be used on a 220-volt line, what should be the hot resistance of the wire?
6. What is the greatest number of 60-watt 115-volt lamps that may be operated safely on a 115-volt line equipped with fuses that blow out at 15 amperes?
7. A 20-volt 100-watt lamp is to be used on a 120-volt line. How much resistance must be placed in series with the lamp?
8. A factory requires 50 amperes at 500 volts. The power comes in over a branch line whose resistance is 0.2 ohm. Determine the voltage of the main line.

AREA SEVEN

How Is the Magnetic Effect of a Direct Current Used?

We have a tendency to take for granted many things about us that we see and use every day. The electric bell, for instance, is so familiar that few of us ever give any thought to what makes the bell ring when we press the button. In this area we shall learn not only that electric current is conducted along a wire but that it sets up another current outside of the wire. This second current, called an electromagnetic current, is a very useful force in electrical instruments and machines.

MAGNETIC EFFECT OF A DIRECT CURRENT

ELECTROMAGNETIC FORCES

The first experiment in electromagnetism. The first experiment in electromagnetism was performed in 1819 by a distinguished Danish scientist by the name of Oersted. In this experiment Oersted used electrical apparatus similar to that in Figure 244, consisting of an electrical circuit and a mounted magnetic needle. The circuit was closed by a commutating switch, or switch that could be closed in two directions, thus reversing the direction of the current. A section of the wire in the circuit, indicated by ab , was stretched over the needle of the magnet. When the switch was closed so that the current flowed from b to a , the north pole of the magnetic needle turned to the west. When the switch was closed so that the current flowed from a to b , the north pole of the needle turned to the east. This experiment attracted much attention at the time because it demonstrated definite relation between electricity and magnetism.

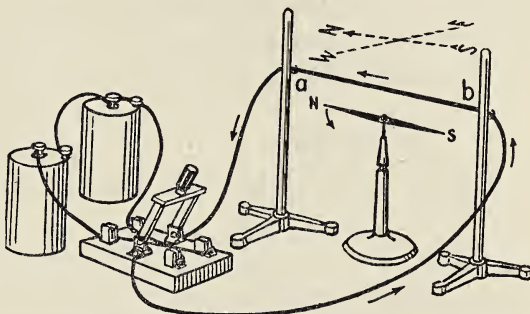


Fig. 244. Apparatus for experiment with electromagnetism.

The magnetic field about a conductor. If we place a wire through a cardboard as shown at the left in Figure 245, sprinkle iron filings on the card, and attach the wire to an electrical circuit, the filings arrange themselves in concentric circles about the conductor. The new arrangement of filings shows that a magnetic field with definite lines of force has formed about

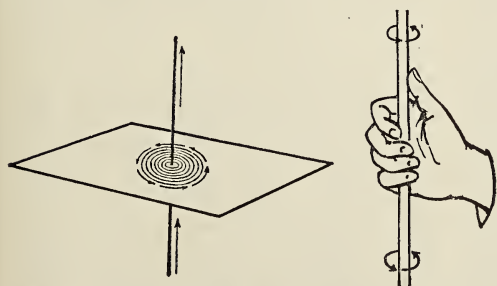


Fig. 245. Magnetic field around electric current and placement of hand to determine direction of current.

PIONEER WORKERS AMONG ELECTRONS

the conductor. To test the direction of these lines of force, we hold a small compass within the field and find that the lines extend counterclockwise. Then we reverse the direction of the current in the conductor and find that the lines of force also reverse to extend clockwise.

A convenient rule for determining the direction of the lines of force about a conductor was formulated by the French scientist Ampère. This rule is stated as follows: *If a conductor is grasped with the right hand with the thumb pointing in the direction of the current, the fingers show the direction of the lines of force in the magnetic field.* The right-hand drawing in Figure 245 shows how this rule can be demonstrated.

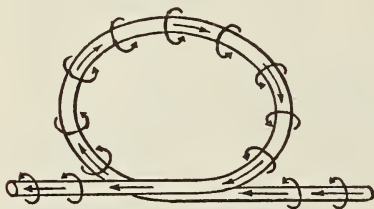


Fig. 246. Flow of current through a wire loop concentrates the lines of force.

within the loop. This happens because the lines of force, which pass around the conductor in the same manner as before, come closer together inside the loop. If we test the magnetic field about

The magnetic field about a loop. If we pass a current through a conductor bent in the form of a loop, as shown in Figure 246, we find that the magnetic field is intensified the loop, we find that it resembles a magnet with north and south poles. Consequently, when we hold a compass on the back of the loop, the north pole of the needle is repelled. If we reverse the direction of the current in the loop and repeat the test, the north pole of the compass is attracted. Thus when a conductor is bent into the form of a coil, called a solenoid or helix, the conductor takes on the properties of a magnet.

This student is experimenting with the behavior of iron filings that have been brought within the magnetic field set up by an electric current.



MAGNETIC EFFECT OF A DIRECT CURRENT

The magnetic field about a solenoid, or helix. If we thread a copper wire through a stiff cardboard in a series of loops in the form of a solenoid, or helix, as shown in Figure 247, and connect the solenoid with an electrical circuit, we obtain another manifestation of electromagnetism. To determine the direction of the lines of force when the current flows in the direction indicated by the arrows in the drawing, we sprinkle iron filings upon the card and find that most of these filings arrange themselves in straight lines lengthwise of the card. A few form concentric circles about the wires at the points where the wires pass through the card. If we bring a compass close to end A of the solenoid, the north pole of the needle is repelled; if we hold the compass close to end B, the north pole is attracted. Thus we find that the solenoid acts as a magnet with the north pole at end A and the south pole at end B.

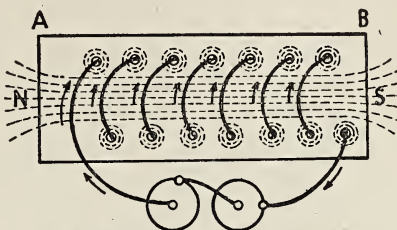


Fig. 247. Lines of force in a solenoid.

When we considered magnetic lines of force, we found that the direction of these lines can be determined by applying a right-hand rule. This rule in a modified form may also be used in finding the direction of the lines of force in a solenoid. In this instance the rule is stated as follows: *If a coil is grasped with the right hand with the fingers pointing in the same direction as the current in the wire, the thumb points in the direction of the lines of force that pass through the coil and in the direction of the north pole of the coil.*

The electromagnet. An electromagnet is merely a solenoid with a core of soft iron placed within the coils. The core of iron becomes magnetized by induction and, as it is a better conductor than air, it sets up many times the lines of force that form in air alone. The core is strongly magnetized only when an electric current flows in the wire. A little magnetism, however, always remains; such magnetism is known as residual magnetism.

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Usually an electromagnet is made with two coils rather than one, with the windings of one coil turning clockwise, and those of the other counterclockwise as shown at the left in Figure 248. Such an arrangement of wiring causes one pole to have the qualities of a south pole and the other the qualities of a north pole. The electromagnet then resembles a regular **U** magnet such as we have already considered. The strength of the electromagnet

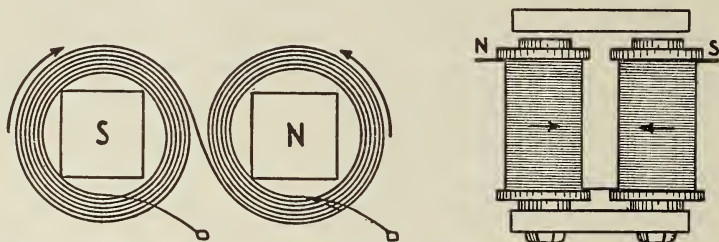


Fig. 248. Two views of an electromagnet. At the left is shown the wiring as viewed from the tops of the poles. At the right is a side view of the magnet, showing how the armature is placed to form an open-core electromagnet.

depends upon the rate of flow of the current, the number of turns of wire, and the length, area, and permeability of the core. Since the permeability of iron is many times that of air, the strength of the electromagnet is increased by means of a soft iron armature extending from pole to pole as shown at the right in Figure 248. Sometimes the armature is placed a short distance from the poles and sometimes directly against the poles. In the former case the arrangement is known as an open-core electromagnet and in the latter case as a closed-core electromagnet.

ELECTROMAGNETIC DEVICES

The lifting magnet. The first magnetic lifting device in this country was made in 1831 by Joseph Henry, who was the first person to insulate wire. Within recent years the lifting magnet has been widely used, especially in steel mills, where it is used at the ends of cranes for lifting huge chunks of iron and steel. The coil in this device is wound around a short steel core, the top of which is fastened to a bowl-shaped steel casting. The lower end of the core acts as one end of the magnet and the rim of the bowl-



Ferdinand Hirsch

This picture shows a lifting magnet, suspended from a movable crane, being used to lift iron scrap into a railroad car. The efficiency of the magnet is apparent.

shaped casting acts as the other, the lines of force passing from the end of the core to the rim. When the device is in use, the pieces of iron or steel to be lifted cling to the lower surface of the rim and serve as paths for the lines of force. When the pieces have been moved to the desired location, the current is cut off and the magnet drops its load. Most lifting magnets are very strong, some lifting as much as 200 pounds per square inch of polar surface.

The electric bell. Another interesting device depending upon the electromagnet is the electric bell, sometimes called the electric doorbell. The essential parts of this device are the bell, the electromagnet, an extension of the armature for striking the bell, and a circuit breaker. When the push button is pressed, a circuit of

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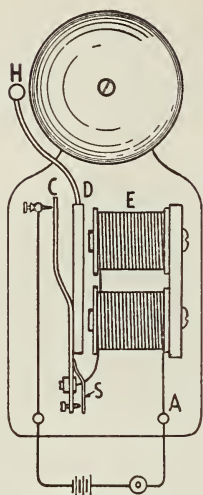


Fig. 249. Electromagnet as used in an electric bell.

electricity enters the instrument at *A* and passes directly to the electromagnet, as shown in Figure 249. This current causes the pole in coil *E* of the magnet to attract armature *D*. As the armature moves toward the magnet, ball *H* on the extension strikes the bell and causes it to ring. At the same time the armature breaks the circuit by pulling arm *C* away from its contact. With the circuit broken, the electromagnet becomes demagnetized, and spring *S* moves armature *D* back to its original position. When this happens, arm *C* again makes contact with the circuit and the complete operation is repeated. The ball *H* continues to strike the bell in rapid succession so long as the push button is pressed.

The electric telegraph. The electric telegraph, as already explained, was invented by Samuel F. B. Morse. The essential parts of the device are the key, shown at the left in Figure 250, and the sounder, shown at the right in Figure 250. The key consists of a brass lever, which the operator presses with his finger to open and close the circuit. When pressing the key he uses the system of dots and dashes commonly known as the Morse code. A spring causes the lever to rise quickly as soon as the pressure is removed. The sounder consists of a U-shaped electromagnet with a steel armature indicated by *A*. This armature is fastened to a brass lever pivoted at *B*. When the operator presses down the key somewhere on the line, the armature

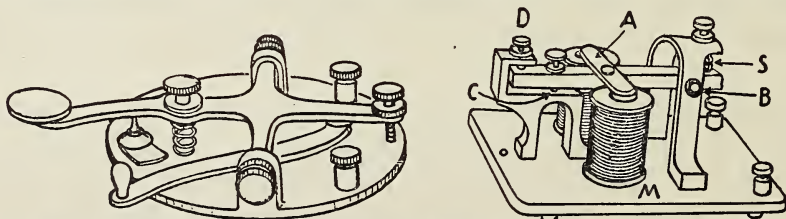


Fig. 250. Diagrams showing the structures and essential parts of an electric telegraph key and an electric sounder. A tap on the key causes a click in the sounder.

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of the sounder at the receiving station moves toward the poles of the electromagnet and pushes down the brass lever, causing it to strike at *C* with a click. The clicks correspond with the dots and dashes used by the operator in sending the message. When the circuit is broken, a spring at *S* pulls the lever up and lifts the armature away from the poles, causing it to strike at *D*.

Besides the parts already mentioned, a telegraph line requires another device known as a relay, shown in Figure 251. This device is used to help operate the sounder. It acts like an electrically operated automobile switch and requires very little current. The relay consists of a U-shaped electromagnet with a very light armature. The coils of the magnet are wound with many turns of fine wire to secure many ampere turns. When current reaches the relay, the electromagnet attracts the armature, causing it to close the switch of a supplementary circuit attached to a battery. This supplementary circuit supplies current for the sounder, causing it to click loudly when messages are received.

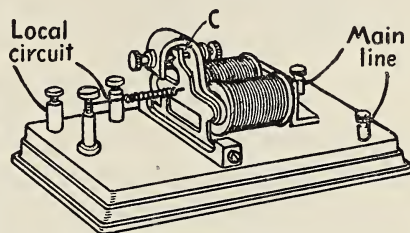


Fig. 251. Diagram of an electrical relay.

The drawing in Figure 252 shows a simple telegraph circuit. When the key is closed at *A* in the sending station, a small cur-

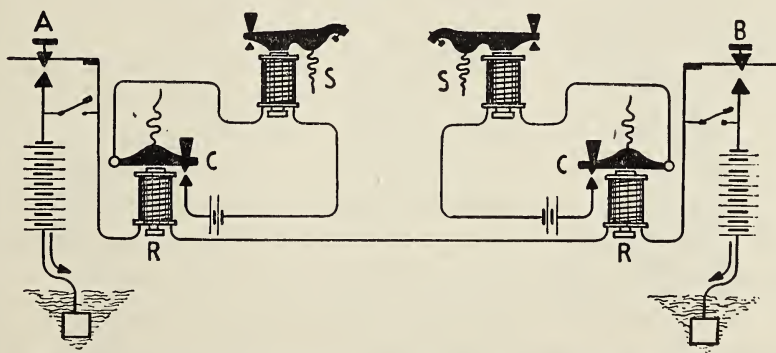


Fig. 252. Diagram showing essential parts and wiring of an electric telegraph circuit.

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rent passes over the line. This current passes into the relay *R*, which closes the circuit at *C* between the local battery and the sounder which clicks loudly.

Within recent years a modification of the telegraph system known as the teletype system has come into use. In this system the operator types the message on a machine resembling a typewriter and the sounder records the message in typewritten form on strips of paper. This system is a great improvement over the original system because it reduces hand operations and thus eliminates many possibilities of error.

ELECTRICAL MEASURING INSTRUMENTS

The galvanoscope. One of the simplest instruments for detecting an electric current and determining its direction is the galvanoscope. This device is somewhat similar to the apparatus that Oersted used in discovering electromagnetism. The essential parts of the device are a coil and a compass mounted within the coil. When current flows through the coil the needle is deflected to the right or the left. The amount of deflection of the needle indicates the strength of the current and the direction of deflection indicates the direction of the current.

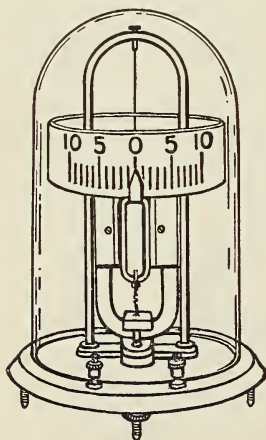


Fig. 253. Drawing of the D'Arsonval galvanometer.

The galvanometer. The instrument most commonly used for measuring a current by means of its magnetic effect is the galvanometer. This instrument is made in several forms, one of the most popular being the D'Arsonval galvanometer shown in Figure 253. The essential parts of this instrument are a permanent horseshoe magnet with the bent end attached to the base, a movable coil, or helix, suspended between the arms of the magnet, and a spring to resist the movement of the coil. Attached to the coil is a pointer which moves on a dial at the front. When an

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electric current passes through the coil, it acquires polarity; its north pole turns toward the south pole of the magnet and its south pole toward the north pole of the magnet. The angle of turn is proportional to the current because the current causes the coil to become an electromagnet. As the coil turns, it moves the pointer on the dial and shows both the direction and the strength of the current. The direction of the current is indicated by the movement of the pointer to the right or the left, and the strength of the current by the distance that the pointer moves from the 0 point on the scale.

The Weston galvanometer, shown in Figure 254, includes a permanent horseshoe magnet with a concave piece of soft iron attached to each arm. Between the pieces of iron are a soft-iron cylinder core and a movable coil of very fine wire wound on an aluminum bobbin pivoted at the top and bottom. The pivots are set in jewels to lessen the resistance caused by friction. Attached to the coil is a pointer that moves across a disk at the front, graduated to show milliamperes, amperes, or volts.

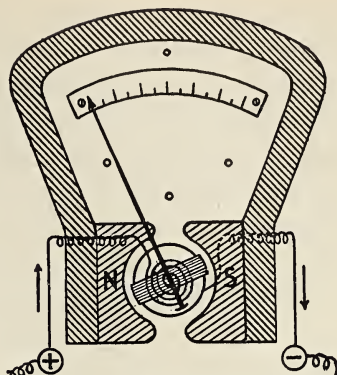


Fig. 254. A Weston galvanometer, showing arrangement of parts.

The turning of the coil is controlled by spiral springs through which the current flows when the instrument is in use. The top spring and the bottom spring are coiled in opposite directions; thus errors that are due to expansion caused by heat are prevented.

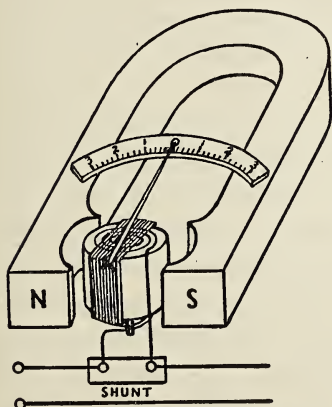


Fig. 255. Diagram showing the arrangement of parts in an ammeter.

The ammeter. Figure 255 shows an instrument closely resembling the Weston galvanometer. It is a low-resistance measuring instrument

known as the ammeter. This instrument is provided with a shunt between the terminals, a connection with very low resistance. Because of this low resistance most of the current passes through the shunt, and only a fraction of the current passes through the coil. Sometimes this instrument is provided with two or three shunts rather than one, so that the resistance may be adjusted to the strength of the current. The instrument is always connected directly in the line of a circuit and never across the circuit. Such a connection is necessary because of its low resistance; otherwise it would cause a short circuit and be burned out. The ammeter measures the rate of flow of an electric current, and the scale is calibrated to show amperes and milliamperes. Since the current passing through the coil is a constant fraction of the total current, the pointer can be made to indicate directly the number of amperes in the total current passing through the circuit.

The voltmeter. Another electrical measuring instrument that closely resembles the Weston galvanometer is the voltmeter, shown in Figure 256. High resistance is created in this instrument by a high-resistance coil attached in series with

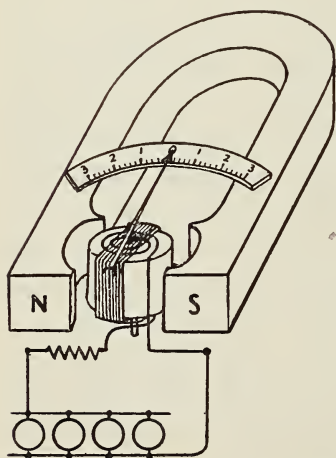


Fig. 256. Diagram showing the arrangement of parts in a voltmeter.

the movable coil. This high resistance is necessary because the voltmeter is used to measure difference in potentials and so must be attached across the line. Were it not for this resistance that is created in the instrument, much of the current would flow through the instrument and reduce the potential difference. Frequently two or three sets of resistance coils are included so that the resistance may be adjusted to the strength of the current. The dial is calibrated to show volts and millivolts, as these are the units that are always used to indicate potential difference.

MECHANICAL ENERGY INTO ELECTRICAL ENERGY

ANSWER THESE QUESTIONS

1. What is the relation between the direction of a current and the direction of the lines of force about a conductor?
2. What happens when a current passes through a conductor in the form of a loop? in the form of a solenoid?
3. What is an electromagnet? What determines the strength of an electromagnet?
4. How is a lifting magnet constructed? How does such a magnet work?
5. What are the essential parts of a telegraph? What is the difference between the sounder and the relay?
6. How does an ammeter differ from a voltmeter?

AREA EIGHT

How Is Mechanical Energy Changed into Electrical Energy?

One of the most interesting changes of energy is the transformation of mechanical energy into electrical energy. In some parts of the country we find generating plants where the energy of steam engines is turned into electricity. In other parts we find huge hydroelectric plants where the energy of falling water is converted into electricity. Large industries and whole communities are now served economically by these new and unlimited sources of electrical energy. On the following pages we shall see how the transformation of mechanical energy into electrical energy is effected.

The principle of induction. By induction we mean the setting up of an electric current in a conductor by means of a magnetic field. In 1819, as we recall, Oersted discovered that an electric current flowing through a conductor causes a magnetic field to form around the conductor. Following this discovery other scientists began to wonder whether the converse might be true; namely, that a magnetic field moving near a conductor might produce an electric current in the conductor. Finally Joseph Henry of this country, in 1830, and Michael Faraday of England, in 1831, discovered that such a current could be produced.

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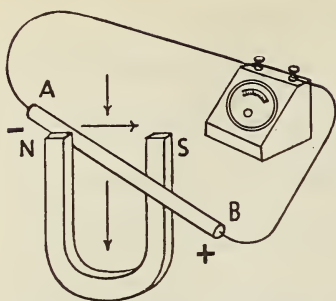
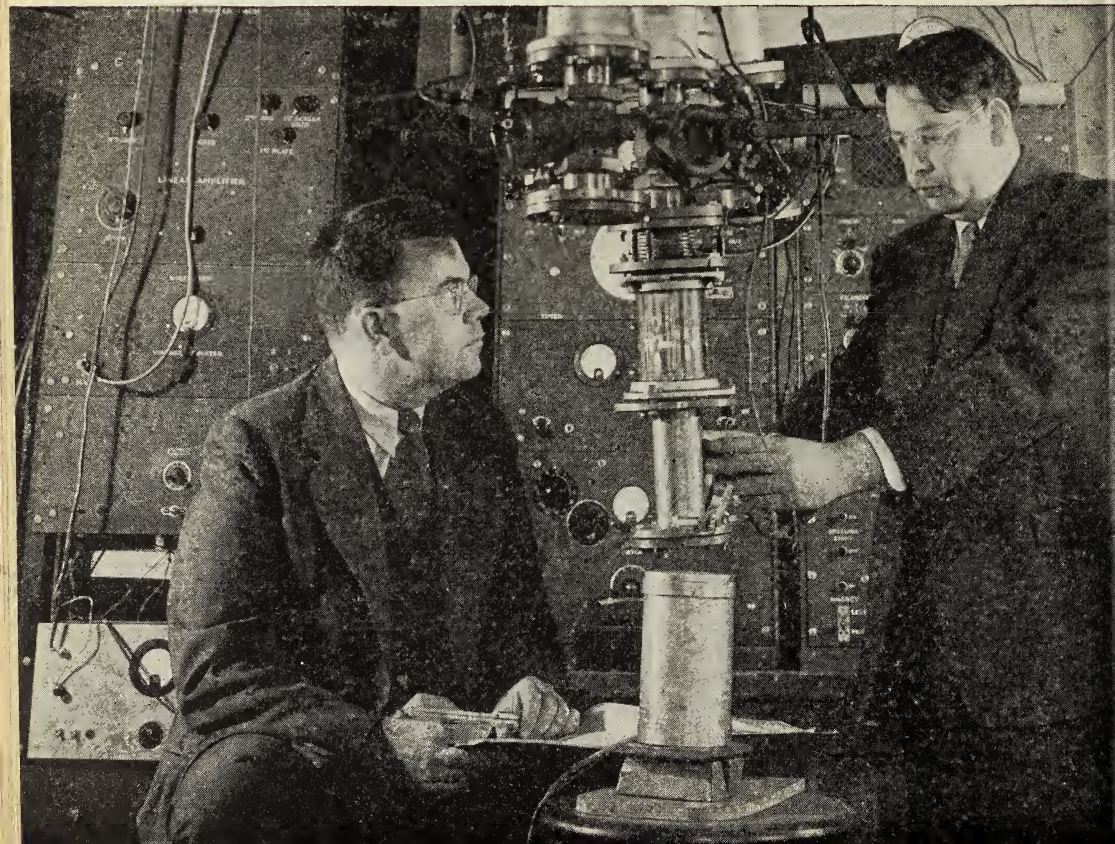


Fig. 257. Experiment showing relation of magnetic poles to the direction of movement of the conductor.

If we set up apparatus consisting of a horseshoe magnet and a copper rod attached to a sensitive galvanometer as shown in Figure 257, we can readily see how the principle of induction works. When the rod and the magnet remain stationary, the galvanometer indicates that no potential difference exists in the rod. If we move the rod downward between the arms of the magnet, however, the galvanometer shows that a potential difference exists in the rod. End *B* of the rod has a positive charge and end *A* a negative charge. If we move the rod upward between the arms of the magnet, a potential difference again exists in the rod, but end *B* is now negative. If we hold the rod stationary and move the horseshoe upward and

Present-day research in electricity requires elaborate equipment and the full-time efforts of research physicists, such as those in this picture. Illustrated here is the tremendous progress man is making in harnessing electric power through science.

Ferdinand Hirsh



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downward, we obtain the same results as when we move the rod. If we move the rod sidewise or move the magnet sidewise, no such condition arises. From these observations we may conclude that whenever we cut lines of force in a magnetic field we set up a potential difference in the conductor. We cut these lines when we move either the rod or the magnet upward or downward, but not when we move either of them sidewise, because the lines of force extend horizontally. There must be relative motion between the conductor and the lines of force.

Another observation from the above experiment is that the direction of the potential difference in the conductor depends upon the direction in which the lines of force are met. The direction of the potential difference also depends upon the relative position of the poles of the magnet; if the poles are reversed, the direction of potential difference is reversed. To determine the direction of the potential difference, scientists commonly use a rule known as Fleming's right-hand rule, which may be stated as follows: *If the thumb, forefinger, and middle finger of the right hand are extended at right angles to one another, and the thumb points in the direction of the motion and the forefinger in the direction of the magnetic field, the middle finger will point in the direction of the current.* Figure 258 shows how the rule works.

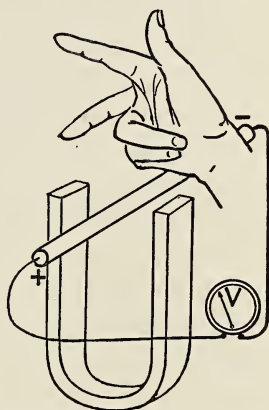


Fig. 258. Application of Fleming's right-hand rule.

If we were to continue our experiment with induction, we should find that we increase the potential difference in the conductor whenever we take the following steps: (1) increase the motion of the rod up or down in relation to the magnet; (2) increase the strength of the field by using a stronger magnet; and (3) increase the number of conductors by using a coil of wire instead of a rod. We may conclude that the amount of potential difference depends upon (1) the rate of motion, (2) the strength of the field, and (3) the number of conductors in series.

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The meaning of Lenz's law. To continue further our study of induction, let us set up apparatus as shown in the drawings in Figure 259. This equipment consists of a bar magnet and a wire helix connected with a Weston galvanometer.

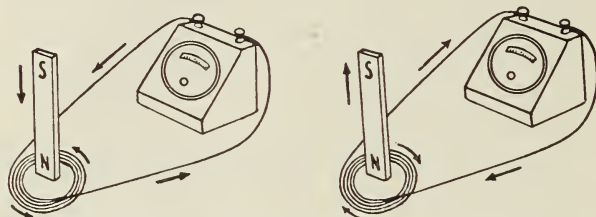


Fig. 259. Experiment indicating the relation of magnetic poles to the direction of flow of the current in a helix.

If we move the north pole of the bar magnet downward toward the center of the helix, as shown in the drawing at left, we find that the induced current in the helix flows counterclockwise. Applying Ampère's right-hand rule to the direction of the current, we find that the north pole of the electromagnet caused by the moving magnet is above the helix. Consequently the north pole of the magnet approaches the north pole of the helix, and the two poles tend to repel each other. If we draw the magnet upward from the center of the helix, as shown in the drawing at the right, we find that the induced current in the helix flows clockwise. Applying Ampère's right-hand rule to the direction of the current, we find that the south pole of the electromagnet caused by the moving magnet is now above the helix. Consequently the north pole of the magnet moves away from the south pole of the helix, or an unlike pole, which it tends to attract. If we reverse the ends of the magnet and perform the experiment again, we obtain the same results. These findings explain a law of induction known as Lenz's law, which may be stated as follows: *Whenever a current is induced by the relative motion of a conductor and a magnetic field, the direction of the current always sets up a field that tends to oppose the motion.*

The electric generator or dynamo. The electric generator operates on the principle of a coil cutting magnetic lines of force. The coil in this case, however, is mounted on an axis so that it may be rotated in the magnetic field by means of a steam engine or

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falling water. To understand how the generator works, let us consider a hand generator, such as shown in one of the drawings in Figure 260. The magnet in these drawings is represented by the poles labeled *N* and *S*, and the armature by the loop of wire labeled *ABCD*. *R*₁ and *R*₂ are two solid rings that rotate with the

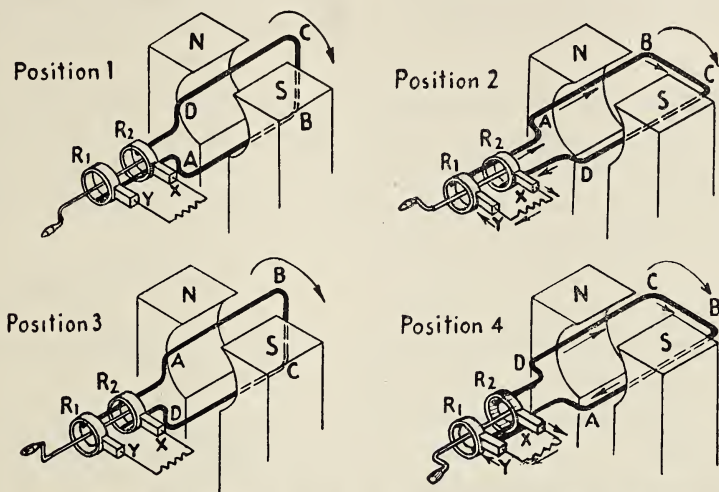


Fig. 260. Diagrams showing the structure and parts of a hand-turned generator. Each of the diagrams illustrates one stage in a complete revolution of the armature.

armature and transfer the current to brushes *X* and *Y*, connected with the external circuit, including a galvanometer. In position 1, *AB* and *CD* move parallel with the lines of force and the galvanometer reading is zero. In position 2, *AB* and *CD* move directly across the lines of force and the galvanometer shows a high potential difference. In position 3, *AB* and *CD* again move parallel with the lines of force and the galvanometer reading is zero. In position 4, *AB* and *CD* again move directly across the lines of force and the galvanometer shows a high potential difference. As we follow the galvanometer in these changes, we find that in position 2 the current flows in one direction and in position 4 it flows in the opposite direction. In other words, the current alternates in direction and hence may be said to be an alternating current. We may indicate the alternating direction by drawing a

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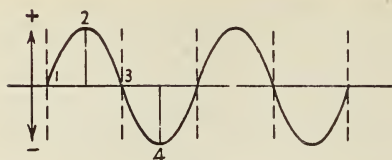


Fig. 261. Graphic diagram showing changes in current due to turning of the armature.

graph such as shown in Figure 261. In this graph the curved line represents the current and the straight line the zero reading on the galvanometer. What does point 2 in the drawing indicate? What does point 4 indicate?

How a direct current is produced. As we have just learned from the foregoing explanation of an electric generator, the current induced by the armature alternates in direction. An alternating current, however, is not suitable for certain purposes, such as charging storage batteries and electroplating, and thus it must be changed to a direct current. The device that is used in changing an alternating current to a direct current is known as a commutator.

In order to understand how a commutator works, let us examine the drawing in Figure 262. In this drawing *AB* and *CD* represent arms of the armature loop and *a* and *b* represent sections of the commutator, arm *AB* being attached to section *a* and arm *CD* to section *b*. During the first half-revolution of the armature loop the end connected with section *a* becomes positive and brush *X*, which is connected with the external circuit, receives a positive charge. During the second half-revolution the loop cuts the lines of force in the opposite direction, and the other end of the loop becomes positive. This end, which is attached to section *b* of the commutator, however, has turned so that section *b* is in contact with brush *X* and brush *X* again receives a positive charge. As a result, even though the direction of the electromotive force changes twice in one revolution of the loop, brush *X* always receives a positive charge.

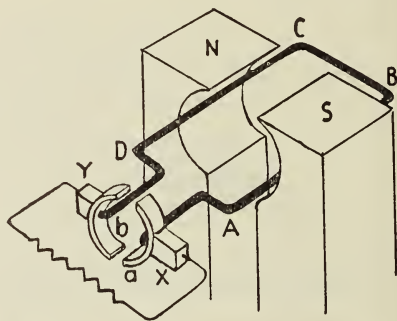


Fig. 262. Diagram showing placement of the commutator for producing direct current.

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In other words, the current from brush *X* always flows in one direction. This current, which pulsates with the half-turns of the armature, is represented by the curve in Figure 263.

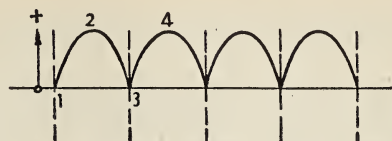


Fig. 263. Graph diagram of a direct pulsating current produced by a dynamo.

For many purposes a steady current is more desirable than the pulsating current represented in the preceding drawing. When two coils at right angles to each other are used in the armature, the electromotive force reaches its maximum value four times during each revolution. The additional electromotive forces overlap one another and provide a more steady current than may be obtained from a single coil. More than two coils may be used if desired.

The direct-current generator. The generator that is used in producing a direct current is known as a direct-current generator, as distinguished from an alternating-current generator. The essential parts of a direct-current generator are the armature, the field, the brushes, and the commutator. The armature, as has already been explained, is the part of the generator in which the electrical pressure is induced. The armature always rotates whereas the field always remains stationary in a direct-current generator. The armature is usually drum-wound; that is, the coils are wound in slots in the core. The core is laminated, or made up of separate disks similar to that shown in the upper drawing in Figure 264. The lower part of the drawing shows a complete armature with the ends of the coils fastened to a commutator. The laminations prevent the formation

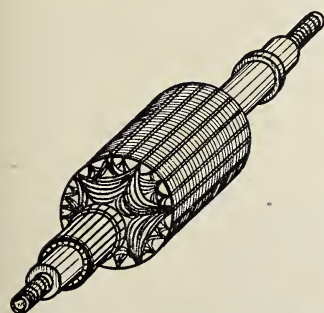
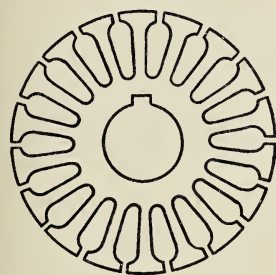


Fig. 264. Diagrams of a laminated disk (above) and a complete armature (below).

of induced currents, known as eddy currents, in the armature. If the armature were solid, such currents would be induced just as currents are induced in the wires, and, since the resistance of the core is comparatively low, the currents would be large, thus heating the armature and lowering the efficiency of the generator.

The commutator, as already explained, is the part of the generator that transforms an alternating current into a direct current. This part is made up of copper segments, insulated from one another and from the core of the armature by mica. There are as many segments in the commutator as there are coils in the armature. Soldered to each segment are the ends of two separate coils of the armature.

The field is the part of the generator that furnishes the lines of force to be cut by the armature. In the type of generator known as the magneto the field is supplied by a permanent magnet, but in other generators it is usually supplied by a strong electromagnet.

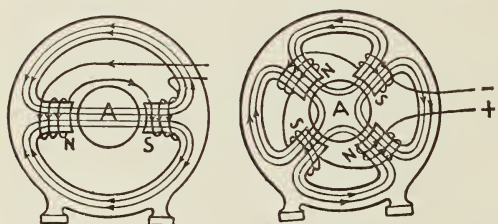


Fig. 265. Diagrams showing wiring of two types of electromagnet, bipolar on the left and four-pole on the right.

The left-hand drawing in Figure 265 shows a two-pole, or bipolar, generator. In this generator two magnet coils are connected in series and wound on two projecting pole pieces. The winding is so done that

one pole becomes a north pole and the other pole a south pole. The lines of force pass from the north pole across to the south pole and return through the frame of the machine. The right-hand drawing shows a multipolar generator, in this instance a generator with four magnet coils connected in series and wound on four projecting pole pieces. The chief advantage of such an arrangement is that it provides a shorter path for the magnetic flux or circuit. Other advantages are that the coils cut more lines of force in one revolution and that four alternations, because of the four poles, are made in one revolution. Because of these advantages this generator produces the same alternations and the same

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voltage at a low speed as would be produced by a two-pole generator running at a higher speed.

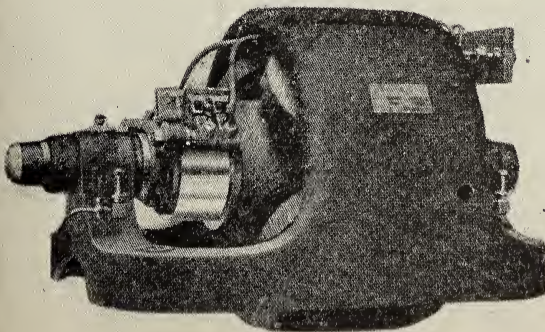
The brushes, or the parts that transmit the current to the outer circuit, are usually insulated carbon blocks. These blocks are stationary, being held in place by brush holders attached to the frame of the generator. The number of brushes in a direct-current generator corresponds to the number of poles in the field.

The voltage of a generator. The amount of the electromotive force produced by a generator depends upon the number of lines of force cut per second. Scientists tell us that a generator must cut 100,000,000, or, as commonly written, 10^8 , lines of force per second in order to produce an electromotive force of one volt. The voltage of a generator depends upon the strength of the field, the number of conductors in series, and the speed of the armature. There is no way of measuring all the electromotive force induced, however, because a voltmeter at the terminals measures only the voltage left after some of the voltage has been used in overcoming the resistance of the armature. This loss of voltage, known as the armature drop, corresponds to the cell drop, previously explained. Armature drop, like cell drop, depends upon the product

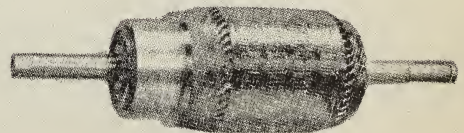
At the left is shown a direct-current generator complete. At the right are three essential parts of this generator, the armature with shaft, the shunt field pole, and coil.

Warner Elevator Manufacturing Co.

DIRECT-CURRENT GENERATOR



ARMATURE



SHUNT FIELD POLE AND COIL



PIONEER WORKERS AMONG ELECTRONS

of the current I and the resistance of the armature R_a , or IR_a . The relation of the total voltage E , the terminal voltage V , and the armature drop IR_a may be shown in the following equation:

$$V = E - IR_a.$$

Types of generators. Generators are classified as self-excited and separately excited, the former being excited by the current generated by the armature and the latter by an outside source. Most direct-current generators are self-excited, whereas alternating-current generators are separately excited. Self-excited generators are of three types, depending upon the wiring; namely, series-wound, shunt-wound, and compound-wound.

The series-wound generator, as shown in the drawing at the left in Figure 266, is so named because the armature and field are con-

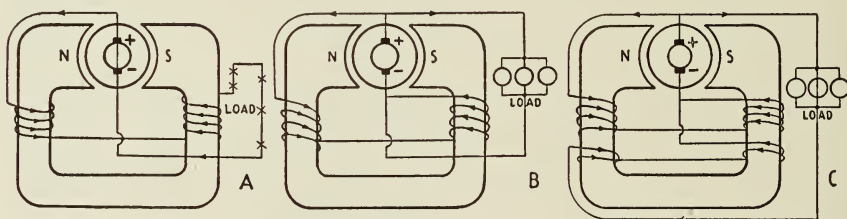


Fig. 266. Diagrams of essential parts and wiring of three types of generators. From left to right, the generators shown are series-wound, shunt-wound, and compound-wound.

nected in series. The wire is comparatively large and only a few turns are used, with the result that the resistance within the generator is small. Such a winding sets up a strong field, the few wires carrying all the current.

The shunt-wound generator, as shown in the center drawing in Figure 266, is so named because the field is connected across the brushes. In this instance a fine wire is used and is given many turns, with the result that the current is small in comparison with the current sent out over the line. A small current through many turns, however, produces a strong field.

The compound-wound generator, as shown in the drawing at the right in Figure 266, is so named because the field is both shunted and connected in series with the load. Such winding

MECHANICAL ENERGY INTO ELECTRICAL ENERGY

keeps the voltage of the generator constant at any load within its range, whereas the voltage of a series-wound generator rises with an increase in load, and the voltage of a shunt-wound generator falls with an increase in load. The series winding contains just enough turns to compensate for the fall in voltage caused by the shunt winding, and thus the voltage remains constant.

The generating system of an airplane. The airplane has a very complex electrical system, consisting of a shunt-wound direct-current generator, a voltage regulator, a current limiter, a cut-out, and a storage battery, as shown in Figure 267. This system

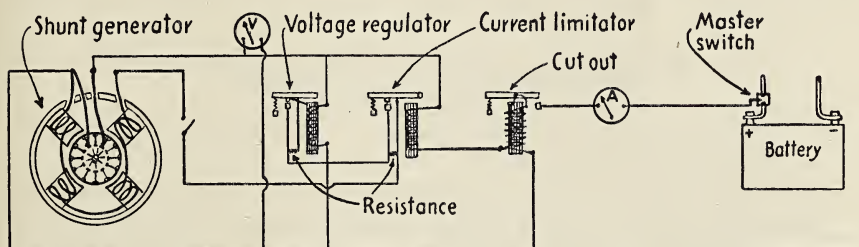


Fig. 267. Diagram showing essential parts and wiring of airplane battery system. This system provides current for the various electrical appliances used in the airplane.

provides current for the lights and in some cases for the ignition system and the radio equipment. The shunt-wound direct-current generator derives power from the engine. The voltage regulator is connected across the main circuit and consists of a mounted lever that makes contact with a high-resistance coil when the voltage becomes too high in the circuit, and thus holds the voltage to a desired level. The current limiter is connected in series with the armature of the generator and the outside circuit. The lever of this device makes contact with a high-resistance coil when the voltage becomes too high in the main circuit and thus prevents the battery from being burned out. The cutout, which consists of a mounted lever and a coil connected directly with the armature, opens the circuit when the engine slows down or stops and thus prevents the storage battery from feeding the current back to the generator.

PIONEER WORKERS AMONG ELECTRONS

The electric tachometer of an airplane. An interesting instrument that operates on the same principle as a generator is the electric tachometer. This device consists of a generator attached to the axis of the propeller so that its rate of rotation varies directly with the rate of rotation of the propeller. The magnetic field is constant because it is set up by a permanent magnet and the number of turns on the armature are constant. Consequently the voltage is directly proportional to speed, or revolutions per minute, of the armatures. Connected across the terminals of the generator is a voltmeter calibrated to show revolutions per minute rather than volts. Thus the tachometer shows at any instant by the readings on the dial how fast the propeller is rotating.

ANSWER THESE QUESTIONS

1. What is meant by induction? How can a potential difference be induced in a conductor?
2. What are the essential parts of an alternating-current dynamo? How does each part work? What is an alternating current?
3. How does a direct-current dynamo differ from an alternating-current dynamo? How is the direct current obtained? What is a direct current?
4. How are the magnetic fields of dynamos excited? What three types of windings are used in the self-exciting type of dynamo?
5. What two factors determine the voltage of a dynamo? How is the armature drop determined?
6. What are the essential parts of the generating system of an airplane? How does each part work?
7. What is a tachometer? How is it constructed?

SOLVE THESE PROBLEMS

1. The armature of a generator has 50 coils of 5 turns each, and makes 600 revolutions per minute. If each conductor cuts 2,000,000 lines of force twice in one revolution, how much e.m.f. is generated?
2. A shunt generator with a terminal voltage of 112 volts delivers 42 amperes to the line. The field coils have a resistance of 180 ohms.
(a) What current flows through the field? (b) What current flows through the armature?

ELECTRICAL ENERGY INTO MECHANICAL ENERGY

3. A generator has an e.m.f. of 125 volts and an armature resistance of 0.2 ohm. Find the terminal voltage of the generator when its armature carries a current of 30 amperes.

4. The armature of a shunt generator has a resistance of 0.3 ohm and it is sending 10 amperes to the external circuit and 0.5 ampere through the field coils. The terminal voltage is 107 volts. Find the following: (a) the armature drop; (b) the armature power loss; (c) the resistance of the field; (d) the power loss in the field; (e) the power sent to the external circuit.

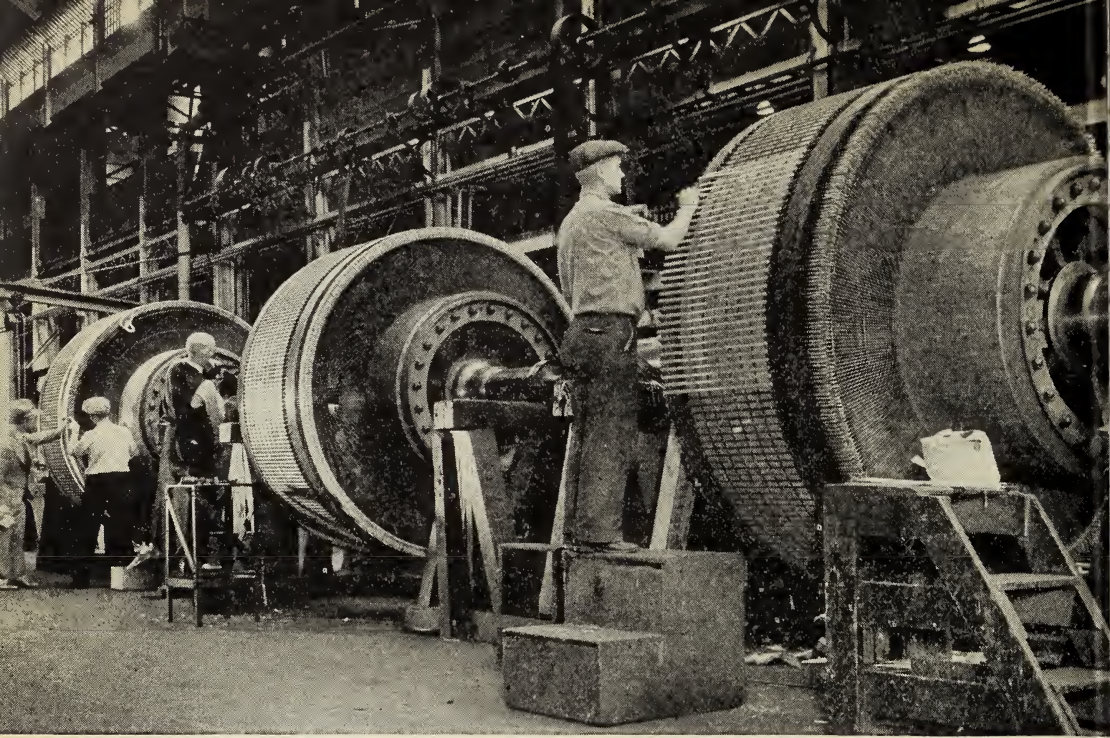
AREA NINE

How Is Electrical Energy Changed into Mechanical Energy?

Whenever a person presses down the starter of an automobile, he causes electrical energy to be converted into mechanical energy. Similarly, whenever a person uses any electrical device such as a pump, vacuum cleaner, or washing machine, he causes electrical energy to be converted into mechanical energy. This area will explain the structure and operation of the electric motor, the machine that always makes the conversion.

The electric motor a generator in reverse. If we connect a direct-current generator with an electrical circuit and turn the switch, we find that the armature rotates and the generator becomes a motor. If we wish, we may even attach a pulley to the rotating axis and cause the motor to do work. If we increase the load, or work done by the pulley, the armature decreases in its speed of rotation. If we attach an ammeter in the circuit, we find that, as the load increases and the speed of the armature decreases, more and more current is required by the motor.

Why does the armature rotate? To understand why an armature rotates, let us set up apparatus for performing a simple experiment. This apparatus includes a horseshoe magnet attached



Ewing Galloway

In this picture are shown three large armatures to be used in electric motors in a steel mill. The worker in the foreground is winding the wire into one of the armatures.

horizontally to a support; a vertical wire suspended between the arms of the magnet with its lower end dipping into a small cup of mercury; and an electrical circuit with one end attached to the wire and the other end touching the mercury, as shown in

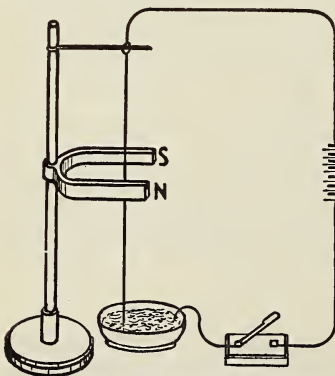


Fig. 268. Apparatus for testing reaction of a wire to a flow of current.

Figure 268. When we cause the current to flow upward in the wire, the wire moves to the left because the surrounding lines of force caused by the current reinforce the lines of force of the magnet on the right and oppose the lines of force on the left. A strong field at the right pushes the wire to the left. When we reverse the current, the wire moves to the right.

Now let us apply the behavior of the wire in the foregoing experiment

ELECTRICAL ENERGY INTO MECHANICAL ENERGY

to the behavior of an armature in a motor. An armature, a cross section of which is shown in Figure 269, is made up of many conductors arranged in a circle about a core. The conductors marked $\odot$ indicate those in which the current flows toward us, and those marked $\oplus$ represent those in which the current flows away from us, or in the opposite direction. According to Ampère's right-hand rule, the top of the armature is the north pole and the bottom of the armature is the south pole. As a result of this

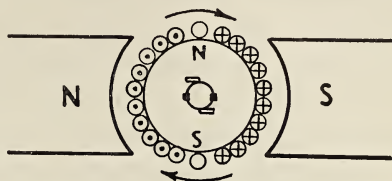


Fig. 269. Cross section of armature, showing relation of current to north and south poles.

polarity, the armature turns clockwise as indicated by the arrows, because its north pole is attracted by the south pole of the magnet and repelled by the north pole of the magnet. Similarly, its south pole is attracted by the north pole of the magnet and repelled by the south pole of the magnet. To keep the armature turning, a commutator attached to the motor reverses the direction of the current in the various conductors of the armature at each half-revolution. Otherwise the armature would come to a complete stop after making a half-revolution.

The tendency of the armature of a motor to rotate is referred to as the torque. The torque of a motor depends upon (1) the number of turns in the armature, (2) the strength of the current flowing through the motor, and (3) the strength of the magnetic field. According to the dictionary what does the word *torque* mean? Why is the torque of a motor especially important?

To determine the relation between the direction in which the armature of a motor rotates and the direction of the magnetic field and the direction of the current, we may apply a rule known as Fleming's left-hand rule. This rule is stated as follows: *If the thumb, forefinger, and middle finger of the left hand are extended at right angles to one another, and the forefinger points in the direction from the north pole to the south pole of the magnetic field and the middle finger points in the direction of the current in a conductor of the armature, the thumb points in the direction of rotation.*

PIONEER WORKERS AMONG ELECTRONS

The back electromotive force of a motor. When the armature of a motor turns, it cuts lines of force, just as the armature of a generator cuts lines of force, and consequently sets up a difference in potential. This difference in potential is known as a back electromotive force because it moves in the opposite direction from the direction of the electromotive force that causes the armature to rotate. In other words, it opposes and decreases the quantity of current flowing through the armature. The quantity of the back e.m.f. depends upon the strength of the field, the number of conductors in the armature, and the speed of rotation. The difference between the applied voltage v and the back e.m.f. e is the net voltage IR . The relation between these three voltages is expressed in the formula $v - e = IR$.

The starting box of a motor. A motor requires a device, known as a starting box, to prevent too strong current from passing through the armature when the motor is started. The starting box is merely a resistance box joined in series with the armature, as

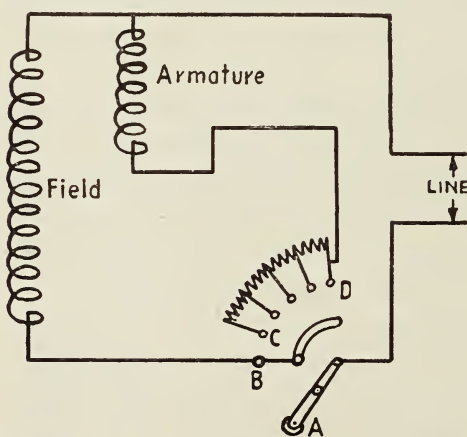


Fig. 270. Diagram of a starting box, showing the wiring system designed to create resistance.

shown in Figure 270. When the switch handle *A* is moved up to point *B*, current flows through the magnetic field, but no current flows through the armature. When the switch handle *A* is moved up to point *C* of the resistance box, the box offers maximum resistance to the current, and only a small quantity passes through the armature. As the handle *A* is moved on toward point *D*, the box offers less and

less resistance to the current and more and more of the current passes through the armature. In the meantime the back electromotive force of the motor helps to provide resistance.

ELECTRICAL ENERGY INTO MECHANICAL ENERGY

The efficiency of a motor. The efficiency of a motor equals the output of the motor divided by the input. To determine the output, we place a brake under the pulley and attach the ends of the brake to spring balances suspended directly overhead, as shown in Figure 271. The difference of the pull on the balances in

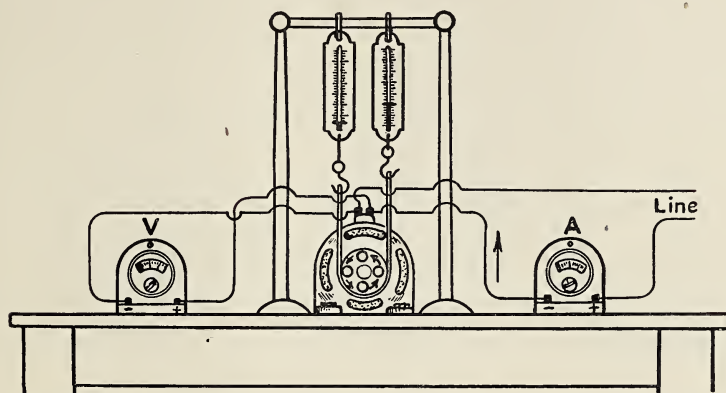


Fig. 271. Arrangement of apparatus for measuring input and output.

pounds, times the circumference of the pulley in feet, times the number of revolutions per minute equals the work done in foot-pounds per minute. This quantity divided by 33,000, the number of foot-pounds per minute in one horsepower, gives the number of horsepower. To determine the input of the motor, we place an ammeter between the motor and the outside circuit and a voltmeter across the terminal of the motor. The product of the readings of these instruments gives the input in watts, and this product divided by 746, the number of watts in one horsepower, gives the input in turns of horsepower. We may express the efficiency of a motor in the form of an equation as follows:

$$\text{Efficiency} = \frac{\text{output horsepower}}{\text{input horsepower}}.$$

The efficiency of a motor for certain types of work depends upon the nature of its winding—whether it is series-wound, shunt-wound, or compound-wound. A series-wound motor has a strong starting torque. The armature and the field receive

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the same current, and the torque is directly proportional to the square of the current. This strong starting torque makes the motor well suited to starting under a load, its speed increasing as the load decreases. In view of these factors the series-wound motor is widely used in automobiles, streetcars, electric locomotives, and other devices that throw a load directly on the motor at the start and vary greatly in speed. A shunt-wound motor has less starting torque than the series-wound motor because the armature and the field receive currents of different strength. After it has acquired its normal speed, it is affected little by the load. It is used in many factories for running machinery. A compound-wound motor combines the advantages of the foregoing motors and hence has less torque and less variation in speed than a series-wound motor and greater torque and greater variation in speed than a shunt-wound motor. The compound-wound motor is used largely in specialized work such as running elevators.

The starting system of the automobile and airplane engines. The starting system of the automobile engine includes a series-wound starting motor, storage battery, and switch, known as the starter. The motor has a high starting torque, directly proportional to the square of the current, a relatively low resistance, and a small back electromotive force. Because of these factors, when a driver puts his foot on the starter, nearly the full force of the battery is used in starting the engine.

The starting system of an airplane engine is similar to that of an automobile except that it is more complicated. Figure 272 shows some of the principal parts, including a series-wound starting motor, storage battery, double switch in cockpit, solenoid starting device, solenoid meshing device, and vibrating booster coil. When the pilot pushes the switch in the cockpit to the first position, the solenoid starting switch closes, allowing current to flow from the storage battery to the starting motor. The starting motor, which usually has a flywheel attached, causes the flywheel to develop a speed of about 12,000 revolutions per minute. When the flywheel has attained this speed, the pilot pushes the switch

ELECTRICAL ENERGY INTO MECHANICAL ENERGY

in the cockpit to the second position. The solenoid meshing device then meshes the gears of the flywheel into the starting gears of the engine and causes the engine to rotate. At the same time the pilot closes the switch to the vibrating booster coil, sending hot sparks to the magneto and thus strengthening the sparks from the magneto to the cylinders of the engine. When the engine begins to rotate, the starting motor becomes disengaged automatically.

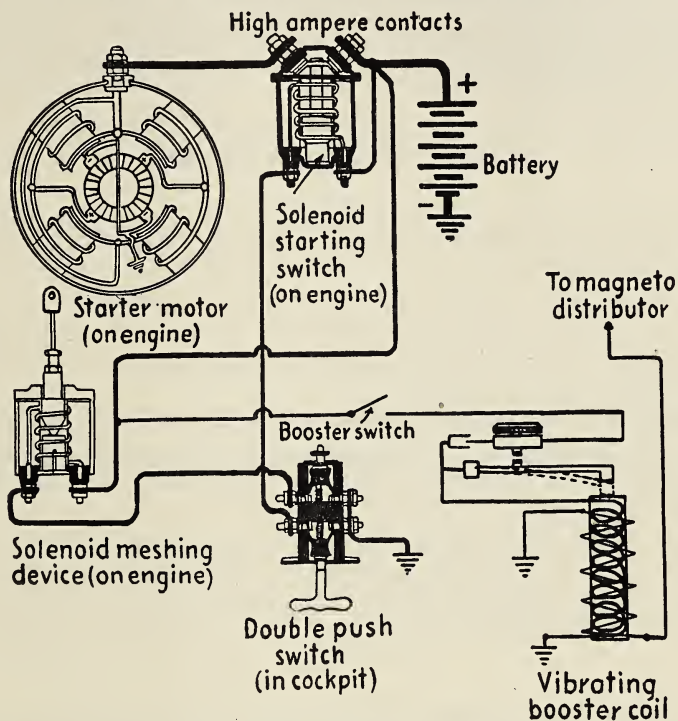


Fig. 272. Diagram showing the essential parts of a starting mechanism.

ANSWER THESE QUESTIONS

1. What happens when a dynamo is connected with a circuit and the switch is closed?
2. What simple experiment shows how a conductor tends to move in an electromagnetic field?
3. How may the turning of an armature in an electric motor be explained diagrammatically?

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4. What is meant by torque? What determines the amount of torque?
5. What rule may be applied to the direction of rotation of an armature?
6. What is meant by back electromotive force?
7. How does the starting box of a motor work? Why is this device necessary?
8. How is the efficiency of a motor determined? How does the winding of a motor affect its efficiency for various kinds of work?
9. How does the starting system of an automobile work? How does the starting system of an airplane work? Which system is the more complicated?

SOLVE THESE PROBLEMS

A

1. What is the efficiency of a 5-HP. motor using 30 amperes on a 220-volt line?
2. A motor is making 1500 r.p.m. and is exerting a pull of 15 lb. on a belt that runs over a pulley 6 in. in diameter. The terminal voltage is 109 volts, and it is using 10 amperes of current. What is the efficiency of the motor?
3. Find the back e.m.f. created in a motor if the electric current through the armature is 10 amperes and the resistance offered by the armature is 0.4 ohm. The line voltage at the terminals of the motor is 110 volts.
4. A shunt generator on a 230-volt line is creating a back e.m.f. of 210 volts. What is the net voltage? If the resistance offered by the armature is 0.4 ohm, what is the quantity of current that passes through the armature?

B

5. A shunt motor operating on a 110-volt circuit develops a back e.m.f. of 90 volts. The resistance of the armature is 0.4 ohm. The resistance of field is 220 ohms. Find the following: (a) the net voltage; (b) the current through the armature; (c) the current through the field; (d) the total current used.
6. A motor has an armature resistance of 0.5 ohm and a field resistance of 220 ohms. The voltmeter across the terminals registers 110 volts and an ammeter shows that the motor is taking 10 amperes. Find the following: (a) the current passing through the field; (b) the current passing through the armature; (c) the net voltage; (d) the back e.m.f.



Ferdinand Hirsh

The operation of this modern automobile depends upon its ignition system, or the electrical circuit that supplies sparks for the cylinders. Should the part known as the coil in this circuit fail to operate, the car would come to a stop.

AREA TEN

How May an Electromotive Force Be Induced in a Conductor without Perceptible Motion?

Every now and then an automobile stalls on a highway because a part of the ignition system, known as the coil, ceases to work. This coil, which generates a secondary current without perceptible motion, is necessary to the operation of the engine. In this area we shall see how such a coil works.

A simple illustration of induction. In the last area we learned how electricity is produced when an armature cuts across lines of force in a magnetic field. Such a process is easy to understand because the armature is in motion and we can readily visualize some of its effects. Now we shall proceed from this process involving motion to one in which a current, known as an induced current, is produced without motion by a device known as an induction coil. This coil consists of two separate coils, one known as the primary coil and the other as the secondary coil.

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To understand how an induction coil works, let us set up apparatus similar to that shown in Figure 273, including a small induction coil made up of a primary coil *P*, attached to a simple cell, and a secondary coil *S*, attached to a galvanometer.

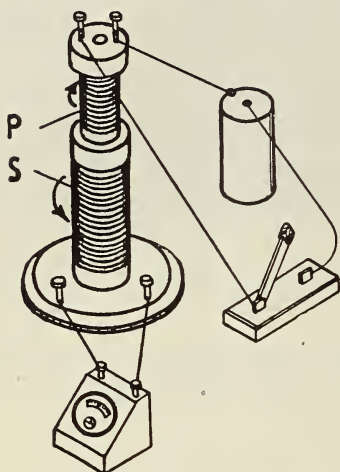


Fig. 273. Primary and secondary coils arranged in a circuit for testing.

When we close the switch, allowing current to flow through the primary coil, the galvanometer needle jumps quickly to one side and then settles back to its zero position. This movement of the needle indicates, of course, that a current of electricity flows through the secondary circuit. This current, which is commonly called an induced current, is formed by spreading lines of force as they build up a magnetic field about the primary coil. Some of these lines of force cut through the turns of wire in the secondary coil and set up an

electromotive force in the coil. This force disappears as soon as the current in the primary circuit reaches its full strength because the lines of force no longer spread through the turns of wire in the secondary coil.

When we open the switch, cutting off the flow in the primary circuit, the galvanometer needle jumps to one side and then settles back as before. The movement of the needle indicates that again an induced current flows through the secondary coil. This current is formed by receding or fading lines of force as the magnetic field collapses. Some of the lines of force cut through the turns of wire in the secondary coil and set up the electromotive force.

In one instance the needle of the galvanometer moves in one direction, and in the other instance in the opposite direction. The direction changes because an induced current always opposes any change in the current in the primary circuit. When the primary circuit is opened, the induced current opposes an increase in the current of the primary circuit, and when the primary circuit is

ELECTROMOTIVE FORCE WITHOUT MOTION

closed, the induced current opposes a decrease in the current of the primary circuit. This behavior of the induced current is in accordance with Lenz's law.

An illustration of self-induction.

Let us consider the principle of self-induction by experimenting with the apparatus shown in Figure 274. This apparatus consists of a six-volt electric lamp attached to the terminals of a large electromagnet and also to the terminals of a storage battery. When we close the switch

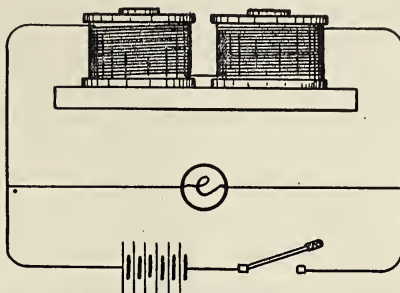


Fig. 274. Apparatus for demonstrating self-induction in a large electromagnet.

of the battery, the lamp flashes for a moment and then assumes a steady brightness. When we open the switch, the lamp flashes again but much more brightly than before. In the first instance the increasing current causes the expanding lines of force to induce an electromotive force in the opposite direction from the voltage of the battery. In the second instance the decreasing current causes the receding lines of force to induce an electromotive force in the same direction as the voltage in the battery. Voltages set up by a changing field, as explained in this experiment, are called voltages of self-induction or inductance. Inductance may be defined as the magnetic property of a circuit that causes the circuit to oppose any change in the current.

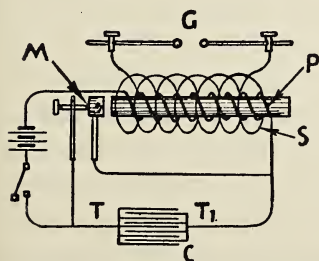


Fig. 275. Apparatus for demonstrating mutual induction.

How the induction coil works. To understand how an induction coil works, let us consider the apparatus shown in Figure 275. Such apparatus is used in changing a low-voltage direct current to a high-voltage alternating current. The primary coil, indicated by *P*, consists of a few turns of heavy, soft iron wire wound in a laminated core. The

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secondary coil, indicated by S , consists of many turns of fine wire wound around the primary coil. When the current passes through the primary circuit, the magnetized core attracts a movable arm and breaks the circuit at M . The core then demagnetizes, and the movable arm swings back, closing the circuit again. As this process continues, the primary circuit is opened and closed repeatedly. Every time that the circuit opens or closes, lines of force cut through the wires of the secondary coil and set up an electromotive force, or induced current. This induced current alternates, or changes direction, with every opening or closing of the primary circuit. Its strength depends upon the number of lines of force cut per second in the secondary coil. The number of lines of force cut per second in turn depends upon (1) the strength of the primary field, (2) the rate at which the field changes, and (3) the number of turns in the secondary coil.

If we attach rods to the secondary coil as shown in the upper part of the drawing, we find that a spark jumps with every break, or opening, of the primary circuit, but that no spark appears with the make, or closing, of the circuit. This observation indicates that in the second instance the electromotive force in the secondary coil is too weak to break down the air resistance of the gap. The difference occurs because the magnetic field of the primary coil collapses more quickly than it forms. The rate with which the lines of force cut through the secondary coil at the break is about 10,000 times as great at the make.

Attached across the gap M of the induction coil, as shown in the foregoing drawing, is a condenser indicated by C . This condenser consists of two sets of plates made of alternate layers of tin foil and paraffined paper. The purpose of the condenser is to absorb the electromotive force of self-induction set up in the primary coil at the break. Such absorption causes the break at M to be more sudden and thus increases the induced electromotive force in the secondary coil. The condenser also helps to demagnetize the core of the primary coil after the break because it discharges back through the battery and the coil and thus sets up an electromotive force in the opposite direction.

ELECTROMOTIVE FORCE WITHOUT MOTION

The ignition system of an automobile. The ignition system of the internal-combustion engine, such as the engine of an automobile, illustrates an important use of the induced current. To understand how this ignition system works, let us examine the drawing in Figure 276. The electric current for the system, which comes from the generator when the engine is running and from the storage battery when the engine is starting, flows to primary coil *P* of an induction coil, as indicated by the arrows.

From this coil the current flows on to the timer, which consists of a cam, or ring, attached to a shaft. This shaft is geared to the crankshaft of the engine and rotates one-half as fast as the crankshaft. The rotation of the crankshaft and the cam causes a lever arm to make and break the circuit at point *a*. Each time the circuit is broken, lines of force cut across

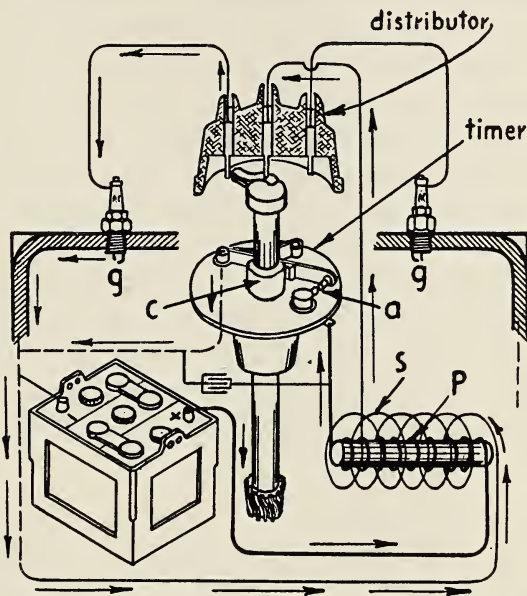


Fig. 276. Diagram of the ignition system in an automobile.

the wires of the secondary coil *S* of the induction coil and set up a strong electromotive force in the secondary circuit. A current then flows from the secondary coil to the distributor, as indicated by the arrows. The distributor contains a rotating arm attached to the shaft that rotates the cam of the timer. This rotating arm makes contact with terminals connected with the spark plugs of the various cylinders. Thus the current is distributed or sent to the cylinders at exactly the right time to produce a spark for igniting the gaseous-fuel mixture in the cylinder. A spark is produced four times in each revolution of the cam.

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The ignition system of an airplane. The ignition system is very similar to that of the automobile except that it is more complicated. Most airplanes have a dual ignition system with separate switches for each part, so that either part or both parts may be used as desired. The dual system has two distinct advantages: (a) it brings about more efficient combustion of the gaseous-fuel mixture in the cylinders, most of which have dual spark plugs and hence require stronger current; (b) it provides an emergency system for use in case the other part fails to work properly.

One type of dual system is known as the dual battery ignition system, shown in Figure 277. The current in this system flows from the battery through the switch and resistance units to the primary coil of the induction coil. From the primary coil the current flows on to the breaker assembly, where a cam opens and closes the circuit. The makes and breaks in the primary circuit cause lines of force to cut across the wires of the secondary coil to induce a current in the secondary circuit. A condenser in the breaker assembly absorbs voltage from the primary circuit when the circuit is broken to prevent the contact points from burning out. From the secondary coil the induced current flows to the

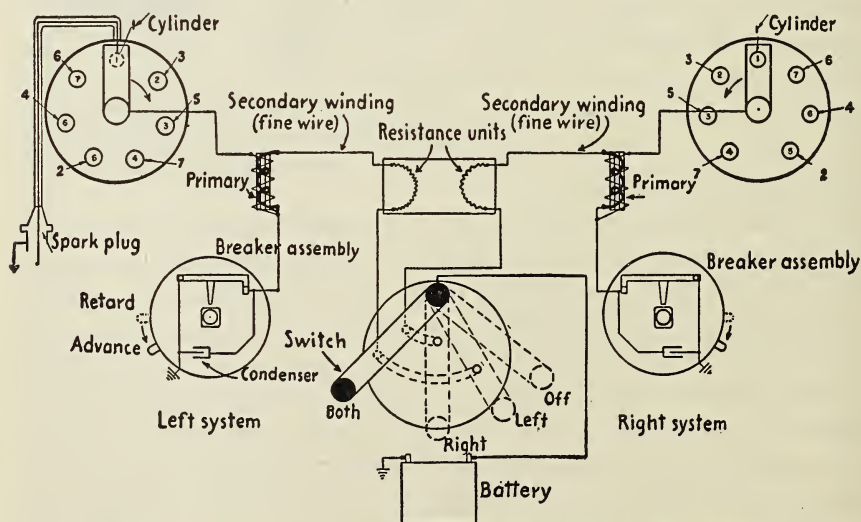


Fig. 277. Diagram of the essential parts in the dual battery ignition system.

ELECTROMOTIVE FORCE WITHOUT MOTION

distributor, which consists of a rotating shaft and arm geared to turn one-half as fast as the crankshaft. The rotating arm makes contact with terminals connected with the spark plugs of the various cylinders and closes the connections at exactly the right time to supply sparks for ignition.

Another common type of dual system is the dual-magneto ignition system, similar to the system just described except that it uses two magnetos as a source of current, as shown in Figure 278. The lower magneto shown in the drawing contains a rotating magnet. This magnet sets up an alternating current, which passes through the primary coil to a breaking system like that of the dual battery system. A rotating cam makes and breaks the primary circuit, thus causing lines of force to cut across the wires of the secondary coil. A condenser absorbs the self-induced current in the primary circuit and prevents the contact points from being burned out. From the secondary coil the induced current flows to the distributor, where a rotating arm makes contact

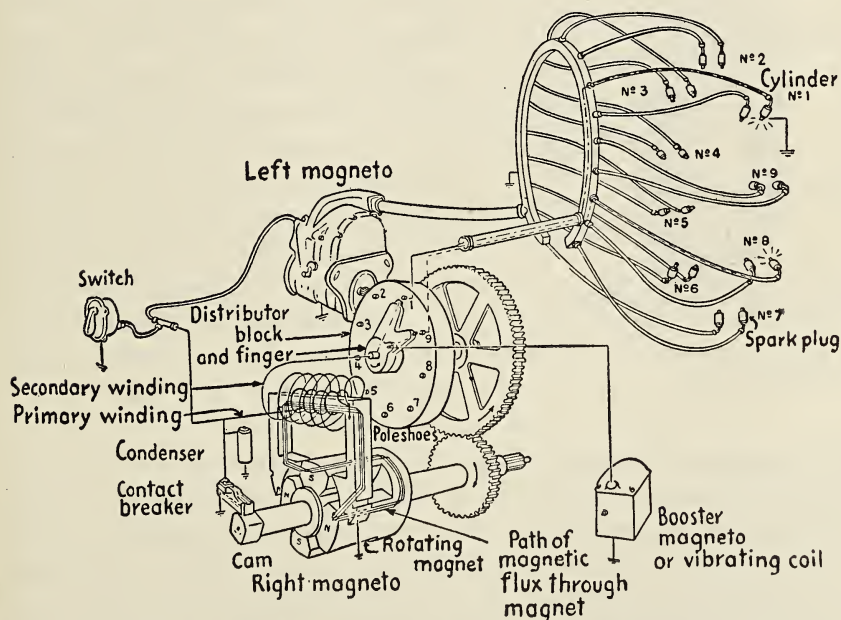


Fig. 278. Diagram of the essential parts in the dual-magneto ignition system.

PIONEER WORKERS AMONG ELECTRONS

with the terminals of wires leading to the cylinders. The contact points in the distributor are arranged to correspond with the firing order of the spark plugs. As the distributor rotates, it distributes the current to each cylinder of the motor.

Included in the dual-magneto ignition system is a vibrating induction coil that intensifies the spark in the cylinders when the motor is starting or becoming "warmed up." This coil, which operates on the same principle as other induction coils, induces a high voltage in the secondary circuit. This voltage passes to the arm of the distributor, where it is sent to the proper spark plugs for use. After the engine has settled down to a steady speed, the circuit from the vibrating coil is no longer needed.

A vital part of the ignition system is the spark plug, or the part that releases the spark in the cylinder. There are two types of spark plugs, the porcelain insulator type, shown in Figure 279, and the mica insulator type. The former type, which is similar to the spark plugs used in the automobile engine, is used in small aircraft, and the mica insulator type is used in large aircraft. The spark plug consists of numerous parts carefully insulated to prevent short-circuiting and rigidly constructed to withstand overheating from the cylinder. How does the spark plug work?

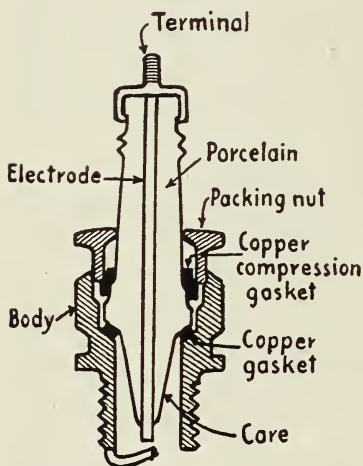


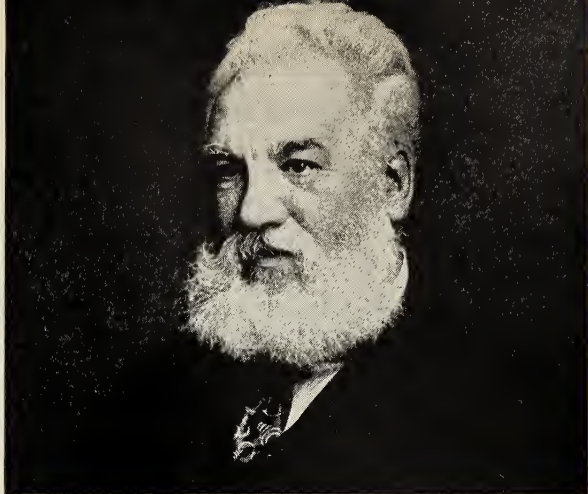
Fig. 279. Diagram of a porcelain insulator spark plug.

The magical telephone. The telephone such as we find in our homes illustrates another important use of the induced current. This device operates upon the principle of changing the strength of a magnetic field and thus causing a disk to vibrate and transmit vibrations to the air. To understand the principle more fully, let us examine the receiver of a telephone. This receiver consists

Alexander Graham Bell

(1847-1922)

Alexander Graham Bell was born and educated in the British Isles, and later came to this country. His chief interest was in the education of the deaf and the science of acoustics. It was his research in this field that led to his invention of the telephone. This is his most important contribution to scientific progress, but he made many other contributions, such as his work on the phonograph.



of a hard rubber core *A*, a permanent U-shaped magnet *B*, two coils of wire *C* and *C'* wound around soft iron pole pieces of the magnet, two terminals *D* and *D'* attached to the outside circuit, and a thin iron disk diaphragm *E*, as shown in Figure 280. When a rapidly changing current flows into the receiver, it sets up magnetic fields about the coils *C* and *C'*. These magnetic fields alternately strengthen and weaken the magnetic fields about the permanent magnet in rhythm with the pulsations of the sound waves falling on the diaphragm of the transmitter. Thus the diaphragm *E* in the receiver is caused to vibrate and transmit vibrations.

The transmitter of the telephone, which operates much like a microphone in radio broadcasting, makes use of carbon in translating mechanical vibrations of a diaphragm into variations in resistance to a current of electricity. To understand the influence of carbon, let us perform an experiment with apparatus such as described on the following page. This apparatus includes a dry cell connected in series with a telephone

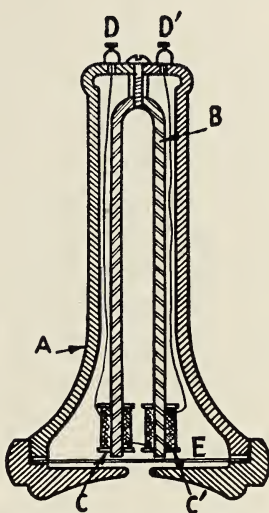


Fig. 280. Parts of an ordinary telephone receiver.

PIONEER WORKERS AMONG ELECTRONS

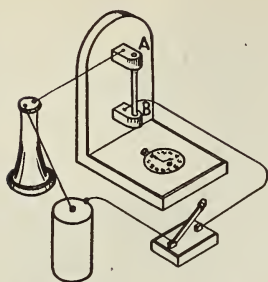


Fig. 281. Apparatus for experiment showing vibrations caused by varying current.

receiver and three pieces of carbon. Two of these, *A* and *B*, are attached to a support, and the third, a rodlike piece, is held loosely between *A* and *B*, as shown at the top of Figure 281. If we place a watch on the base of the support, we find that its ticking varies the pressure of the rods, which in turn varies the current. The changing current passes through the two coils of the receiver and thus strengthens or weakens the magnetic field of the permanent magnet.

The changes in magnetism cause the diaphragm to vibrate, and we hear the ticking distinctly.

The essential parts of the transmitter of a telephone are the mouthpiece *A*, a thin iron diaphragm *B*, a carbon plate *C*, a box filled with granules of carbon *D*, and a rear cover plate *E*, as shown in Figure 282. When a person speaks into the mouthpiece, the diaphragm transmits the vibration through carbon plate *C* to the box of carbon granules in *D*. The carbon granules in turn cause variations in resistance in the electrical circuit and hence vary the strength of the current in accordance with the vibrations of the diaphragm.

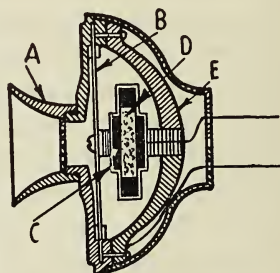


Fig. 282. Telephone transmitter with parts exposed.

This picture shows the latest model of a telephone instrument, called a "cradle" phone. In this instrument, the receiver and transmitter are put together in one piece.

Ferdinand Hirsh



ELECTROMOTIVE FORCE WITHOUT MOTION

Many telephones connected with small telephone exchanges have dry cells connected in series with the transmitter and a primary coil. The varying current from the transmitter induces a corresponding current in a secondary coil. This induced current passes over the line, and the original current merely passes on to the cells. The telephones in larger cities have no dry cells, the current being supplied by a large central storage battery. In this case no induction coil is used with the transmitter, the pulsating current from the transmitter passing directly to the receiver.

The telephone circuit. Now let us summarize our understanding of the telephone by considering what happens in a telephone circuit such as shown in Figure 283. When a person speaks into the transmitter *T*, a variable current, as already explained, passes through primary coil *P* and induces an irregular alternating current in coil *S*. This irregular current travels over the line to the coils in the receiver *R*. These coils set up magnetic fields that strengthen or weaken the magnetic field of the permanent magnet, causing the diaphragm to vibrate in harmony with the vibrations of the diaphragm of the transmitter. These vibrations transmitted to the air and from the air to the ear produce sounds similar to those made at the mouthpiece.

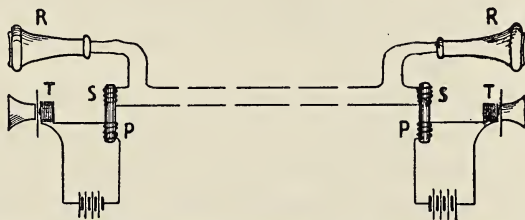


Fig. 283. Telephone transmitter in local battery system.

ANSWER THESE QUESTIONS

1. What simple experiment shows how induction takes place without motion?
2. What is an induction coil? How does the induction coil work? Why is a greater electromotive force induced at the break than at the make?
3. Why is a condenser used with an induction coil? How is a condenser constructed?

PIONEER WORKERS AMONG ELECTRONS

4. What are the essential parts of the ignition system of an automobile? How does the ignition system work?

5. How does the ignition system of an airplane resemble that of an automobile? What is meant by a dual battery system? a dual-magneto system?

6. How does the transmitter of a telephone work? How does it depend upon induction?

7. How does the receiver of a telephone work? Why do the vibrations of the diaphragm in the receiver correspond with those of the diaphragm in the transmitter?

SUMMARY

An electric current is a flow of electrons along a conductor caused by a difference of electrical pressure, or electromotive force (e.m.f.). According to Ohm's law the strength of current = $\frac{\text{electromotive force}}{\text{resistance}}$. The unit of flow is the ampere, the unit of

electromotive force the volt, and the unit of resistance the ohm.

The resistance of a conductor is directly proportional to its length and inversely proportional to its cross-section area or to the square of its diameter. When conductors are connected in series: (1) the current, or rate of flow, is the same at all points; (2) the voltage, or fall of potential, across the different parts is directly proportional to the resistance of the parts; (3) the total voltage in the circuit is equal to the sum of the voltages of the parts; (4) the resistance in the circuit equals the sum of the resistances of the parts. When conductors are connected in parallel: (1) the voltage is the same in each branch of the circuit; (2) the total current is the sum of the currents flowing through the branches; (3) the total resistance is less than the resistance of the smallest branch.

Electricity is frequently created through chemical action in a conducting solution known as an electrolyte. The molecules of the electrolyte break up into charged ions that move from a positive electrode to a negative electrode. The resistance of cells equals the total electromotive force minus the voltage used in the external circuit divided by the current. When similar cells

are connected in series, the current equals the electromotive force times the number of cells divided by total external resistance (R_e) plus the internal resistance ($R_i \times N$). When similar cells are connected in parallel, the current equals the electromotive force of one cell (E) divided by the external resistance (R_e) plus the internal resistances divided by the number of cells $\frac{(R_i)}{N}$.

When electricity passes through a liquid conductor, a process known as electrolysis takes place, in which ions move from the positive electrode to the negative electrode. This process forms the basis for such industrial activities as electroplating, chromium plating, electrotyping, and the refining of metals. According to Faraday's law *the mass of any substance carried through a solution is proportional to the product of the current and the time it is allowed to flow*. Electricity is stored in a device known as the storage battery.

Electric power is the rate at which electrical energy is used and equals the rate of flow times the potential difference. Electrical energy is calculated in joules, or volts times amperes times seconds. For commercial purposes the energy is measured in kilowatt-hours according to the following equation:

$$\text{Kilowatt hours} = \frac{\text{amperes} \times \text{volts} \times \text{hours of time}}{1000}$$

Electrical energy is changed into heat energy when used in overcoming electrical resistance. The heat equivalent of electrical energy is the quantity of heat generated from one joule of electrical energy per second. Among the many practical devices that produce heat for electrical energy are the electric iron, the electric percolator, and the electric furnace. The devices that produce light are the incandescent bulb and the carbon lamp.

Electromagnetism is the name given to the magnetic force about a conductor carrying a current of electricity. The direction of the magnetic lines of force may be determined by Ampère's right-hand rule stated as follows: *If a conductor is grasped with the right hand with the thumb pointing in the direction of the current,*

PIONEER WORKERS AMONG ELECTRONS

the fingers show the direction of the lines of force in the magnetic field. According to Ampère's rule the north pole of the electromagnetic field may be determined as follows: If a coil is grasped with the right hand with the fingers pointing in the same direction as the current in the wire, the thumb points in the direction of the lines of force that pass through the coil and in the direction of the north pole of the coil. The strength of an electromagnet depends upon the strength of the current, the number of turns, and the size and material of the core.

The generator is a machine used to change mechanical energy into electrical energy, either direct or alternating current. When relative motion exists between a conductor and a magnetic field, an electromotive force is produced. Lenz's law explains the behavior of an induced current as follows: *Whenever a current is induced by the relative motion of the conductor and a magnetic field, the direction of the current always sets up a field that tends to oppose the motion.* Fleming's right-hand rule explains the direction of an induced current as follows: *If the thumb, forefinger, and middle finger of the right hand are extended at right angles to one another, and the thumb points in the direction of the motion and the forefinger in the direction of the magnetic field, the middle finger will point in the direction of the current.*

An electric motor is a machine that changes electrical energy into mechanical energy. The direction of motion may be determined by Fleming's left-hand rule, which is stated as follows: *If the thumb, forefinger, and middle finger of the left hand are extended at right angles to one another, and the forefinger points in the direction from the north pole to the south pole of the magnetic field and the middle finger points in the direction of the current in a conductor of the armature, the thumb points in the direction of rotation.* The back electromotive force of a motor is the voltage induced in the rotating armature that opposes the impressed voltage. The net voltage equals the difference between the impressed voltage and the back electromotive force.

An electromotive force is produced in a conductor without perceptible motion by means of an induction coil. In such a case

PROBLEMS

a changing current in a primary coil induces a current in a secondary coil. The voltage induced in the secondary coil depends upon (1) the number of turns in the secondary, (2) the strength of the primary field, and (3) the rate at which the field changes.

In what respects is a current of electricity in a conductor like the flow of water in a pipe?

Why are dry cells inadequate for continuous service?

Why is it important that the internal resistance of a dry cell be very small?

How has electrolysis helped to build up the aluminum industry in America?

Is electric power or electrical energy charged for on electric bills?

What is a short circuit? Why is it dangerous? What safety devices are used in the event of a short circuit?

What are the advantages of the fluorescent lamp over the incandescent filament?

What are some of the changes made in the last century in ways of living due to the electromagnet?

Why does the current flowing through a motor increase as the load on the motor increases?

Why is a series-wound motor used as the starting motor in an automobile?

SOLVE THESE PROBLEMS

1. If an electric heater has a resistance of 20 ohms, what current does it take on a 115-volt line?

2. What is the resistance of a mile of aluminum wire whose diameter is 0.1 inch if the resistance of aluminum is 17.4 ohms per mil-foot?

3. How much current will flow through a lamp whose resistance is 280 ohms, a motor whose resistance is 2 ohms, and an electromagnet whose resistance is 8 ohms, connected in series, if 115 volts are applied? What is the current? What is the voltage across the lamp? across the small motor?

4. What current will flow in a circuit of 6 dry cells in series and an electromagnet of 1.64-ohm resistance if the e.m.f. of each cell is 1.5 volts and the internal resistance of each cell is 0.05 ohm?

5. If 5.93 g. of copper are deposited per hour in an electroplating cell with a copper anode and a zinc cathode in series with an ammeter, what should be the reading of the ammeter? (The K for copper is 0.000329 g. per ampere-second.)

PIONEER WORKERS AMONG ELECTRONS

6. How much heat is generated in 60 min. by a heating unit that takes 5 amperes on a 115-volt circuit?

7. If the resistance of the armature of a shunt generator is 0.04 ohm, its field has a resistance of 200 ohms. When the generator is delivering 40 amperes to the line, and it has a terminal voltage of 100 volts, what current is flowing through the field? What is the current in the armature? How much voltage is used in sending the current through the armature? How much power is lost in the armature?

8. What is the efficiency of a 5-HP. motor that takes 40 amperes from a 110-volt line?

INVESTIGATIONS

1. Cut an old dry cell in two lengthwise. Why is the resistance of the cell very low? Is a good dry cell dry? Test the voltage of a flashlight cell with a voltmeter and compare its voltage to the voltage of a good common-size dry cell. Will the flashlight give as much current? Explain.

2. Obtain a worn-out storage battery and take out the plates. Notice the number of plates connected together for each terminal. Which is positive and which is negative? Why are there more negative plates than positive? Notice the white crust. What is this crust? What is its effect on cells? What caused its deposit?

3. Obtain an old automobile generator. Take it apart and notice the armature and field windings. Is it a series- or a shunt-wound generator? Cut the armature to show how the armature and the lamination of the core are wound. (The armature of a vacuum-cleaner motor would serve for this.)

4. Obtain the starting motor from a junked automobile. Have it opened so that the parts may be seen. Is the motor series- or shunt-wound? Tell why. Why are the conductors on the armature so large? Will the armature have a large back electromotive force? Tell the advantage of this. What size of wire is used in the field? Give reasons for this. This motor sometimes takes 200 amperes from a 6-volt storage battery. Can you explain this from the above?

5. Investigate the use of an induction coil in sending an electrical discharge through a tube in which the pressure of the air is varied and through tubes containing neon and other gases.



This picture illustrates one of the ways in which electricity contributes to our modern way of living. Important work in factories is carried on under ideal lighting conditions.

Modern Workers among Electrons

ALADDIN AND HIS LAMP

Do you remember the story of Aladdin and his lamp? When the lamp was rubbed, a genie appeared and exclaimed, "What do you desire? I am ready to obey you as your slave." Nothing was too difficult for the genie to accomplish. In modern times there has appeared a new genie, more powerful than the one that served Aladdin. We can summon this modern genie merely by turning

**UNIT
TEN**

MODERN WORKERS AMONG ELECTRONS

a switch or pressing a button, and it will perform miracles so wonderful that Aladdin could not even have dreamed of them. Its power seems unlimited and yet so quietly does it work that we give little thought to it until we need its service.

The modern genie is a reality rather than the filmy product of the imagination. This genie, known as electricity, is the product of research carried on by many men of science. First one, applying the principles of scientific method, made a contribution, and then another, until electricity became a real working force in the world. The result of these efforts is astounding, for electricity has revolutionized the world. On one front we see it lighting homes and city streets, and on another front providing heat for cooking food. Again, we see it providing power for turning the wheels of factories or for running electric trains. No wonder, then, that electricity may be likened to a genie, for it does indeed play the role of magic.

Electric current, as you recall, is developed and used in two forms, direct current and alternating current. Both currents serve definite purposes, but alternating current is more widely used than direct, about 95 per cent of the electrical energy being supplied in this form. In this unit you will study alternating current, how it is produced, and how it is used in carrying on useful work in the world. More specifically, you will consider the topics indicated by the following questions:

AREAS OF STUDY

- 1. What is the difference between an alternating current and a direct current?***
- 2. How is an alternating current measured?***
- 3. How does an alternating-current generator work?***
- 4. How do motors work on an alternating current?***
- 5. How do transformers make electric power available?***

AREA ONE

What Is the Difference between an Alternating Current and a Direct Current?

In the previous unit we found that dynamos produce two kinds of current, alternating current and direct current. This area will explain the difference between these two kinds of current and point out some of their specific uses.

The relation of currents to electrons. A current of electricity, as we have learned, is a flow of electrons along a conductor. In an alternating current the electrons move back and forth through very short distances. In a direct current the electrons move continuously in the same direction. This difference in the movement of electrons accounts for the different effects produced by the two currents. The heating effect of the currents is the same, but they produce different magnetic effects. Only the direct current may be used to produce chemical effects, because the ions in an electrolyte must move in a continuous direction.

Because of the difference in effects alternating current is used more widely than direct current. Moreover, alternating current can be developed and distributed more cheaply than direct current. In general, alternating current is used for lighting buildings and streets, for heating toasters, irons, and the like, and for running machines. Direct current is used in running elevators and streetcars, electroplating, refining metals, and the like.

An experiment with alternating and direct currents. To understand better the real difference between the alternating and the direct current, let us set up apparatus similar to that in Figure 284. This apparatus consists of an electrical circuit

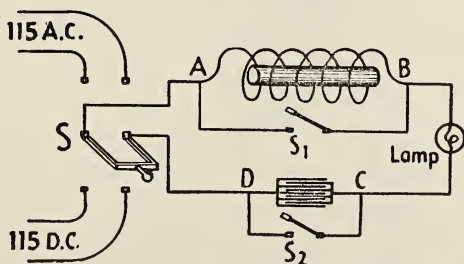


Fig. 284. Diagram showing apparatus for experiments with both alternating and direct currents.

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that includes a large electromagnet with a removable core, a condenser, a 25-watt lamp, and a double-throw switch. Shunts with single switches S_1 and S_2 , respectively, are provided around the electromagnet and around the condenser. The double-throw switch S is so arranged that it may make contact with either an alternating current or a direct current of 115 volts.

First we close the single switches S_1 and S_2 and then close the double-throw switch making contact with the direct current. The lamp shines brightly. If we pull the core out of the electromagnet, the lamp continues to shine brightly. From this behavior we may conclude that the electromagnet offers little opposition to the direct current. Next we close S_1 and open S_2 , connecting the condenser in series with the lamp. In this instance the lamp does not light, because a direct current will not flow in a circuit containing a condenser.

When we have completed these observations, we close both the single switches, S_1 and S_2 , and also the double-throw switch making contact with the alternating current. The lamp shines brightly. If we open switch S_1 , the lamp glows only dimly, but if we pull the core out of the electromagnet, it shines more

The large coil in this picture carries an alternating current. As the student removes the iron core from the coil, the opposition is decreased and the increasing current causes the light to become brighter. The light becomes dim when the core is replaced.



ALTERNATING AND DIRECT CURRENT

brightly. From this behavior of the lamp we see that the electromagnet offers added opposition to the current. This opposition is caused by back electromotive force that is formed by self-induction in the coil. Next we close S_1 and open S_2 , thus connecting the condenser in series with the lamp. The lamp lights, but with less brilliance than when S_2 is closed, showing that the condenser offers opposition to the alternating current.

From this experiment we find that the electromagnet offers opposition to an alternating current which it does not offer to a direct current. The condenser, on the other hand, offers some opposition to an alternating current and does not allow a direct current to pass.

Special consideration of the alternating current. Since the alternating current is most widely used and therefore the one with which we are chiefly concerned, let us give special attention to certain factors associated with this current. A study of these factors will help us to understand better the alternating current.

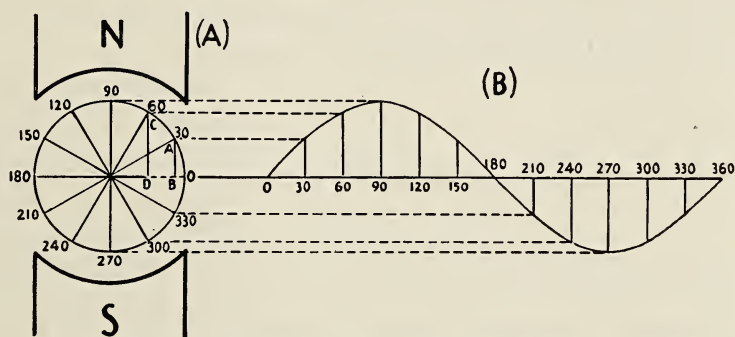


Fig. 285. Sine curve representing alternating current from the armature.

Sine curve. When the armature of an alternating-current dynamo rotates, it produces, as we know, an alternating electromotive force that causes an alternating current to flow through the generator. The left portion of Figure 285 represents the armature of a dynamo making one complete revolution, and the right

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portion of the drawing, known as a sine curve, represents the current. The drawing of the armature is split into twelve parts, each part representing 30° of the 360° in a complete revolution. Lines such as AB and CD , drawn from the base line 0° to 180° , represent by their height the rate at which the armature cuts the lines of force at such points. Horizontal lines drawn from these points determine the height of vertical lines shown in the right part of the drawing. The spaces between the vertical lines correspond to the spaces between the points on the circumference of the circle. The line drawn through the intersections of the horizontal lines with the vertical lines is the sine curve.

Cycle. The curve from 0° to 360° represents a cycle, which is one complete series of changes. At the end of 360° the coil is in the same condition as at the beginning. In a two-pole generator there is one cycle for each revolution. In a four-pole generator there are two cycles for each revolution. This is equally true if the field rotates instead of the armature.

Frequency. The frequency is the number of cycles per second, the most common frequency being 60.

Alternations. There are two alternations for each cycle. A 60-cycle current alternates 120 times per second.

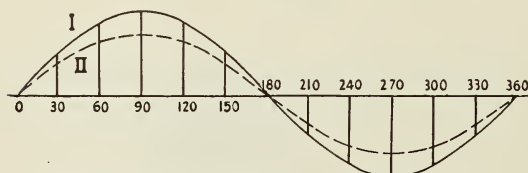


Fig. 286. Graphic illustration of currents in phase.

Phase. Any point or position in a cycle is the phase, and it is measured in degrees. Two currents of the same frequency are in the same phase when they rise and fall together and pass in the same direction through their maximum and zero values at the same instants, as shown in Figure 286. They are out of phase when one current for some reason or other lags behind the other.

Induced electromotive force versus applied electromotive force. Whenever a changing current flows through a coil, as we have learned, it sets up a changing field about the coil, in which the

ALTERNATING AND DIRECT CURRENT

lines of force alternately swell and collapse. At the same time, a back electromotive force forms in the coil from self-induction, or inductance. This back electromotive force opposes the current and causes it to lag behind the applied voltage, as shown in Figure 287. In this drawing E represents the applied voltage, i the current, and e the induced electromotive force. By how much,

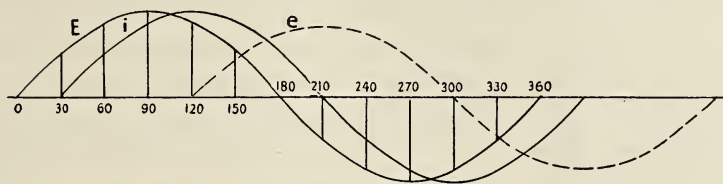


Fig. 287. Diagram illustrating effect of inductance upon the flow of current.

according to the drawing, does the current lag behind the applied voltage? By how much does the induced electromotive force lag behind the current?

The unit of inductance is commonly called the henry in honor of its discoverer, Joseph Henry. The inductance of a current is one henry when a change of one ampere per second in the rate induces an electromotive force of one volt. The opposition due to inductance, known as reactance, caused by a back electromotive force is measured in ohms.

Comparing the resistance of currents. When a direct current is sent through a circuit, it is opposed only by the resistance of the circuit. In other words, no self-induction takes place and therefore no back electromotive force forms to impede its progress. The rate of flow, as measured in terms of Ohm's law, equals the voltage divided by the resistance, or $I = \frac{E}{R}$.

When an alternating current flows through the circuit, the flow is opposed both by the resistance of the conductors and by the reactance, or back electromotive force from self-induction. The total opposition set up by these two forms of opposition is known

MODERN WORKERS AMONG ELECTRONS

as impedance. Offhand we might think that we can calculate the impedance merely by adding the circuit resistance and the reactance, but this is impossible because the two oppositions act in different phases. The circuit resistance, indicated by R , acts in phase with the current, but the reactance, indicated by X ,

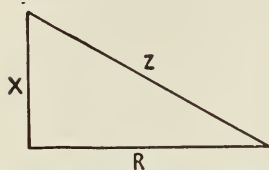


Fig. 288. Right-angle triangle for determining impedance.

lags 90° behind the current. Thus the two forces act at right angles to each other and may be plotted as the sides of a right-angle triangle, as shown in Figure 288. The hypotenuse of the triangle, indicated by Z , then represents the resultant, or the impedance, of the two forces. To calculate the value of Z in such a triangle, we extract

the square root of the sum of the squares of sides R and X . Expressing the relationship in the form of an equation, we have

$$Z = \sqrt{R^2 + X^2}.$$

Both the circuit resistance and the reactance are measured in ohms, and therefore the impedance is indicated in ohms. When scientists apply the equation for Ohm's law to an alternating current, they always substitute Z for R to indicate the character of the resistance.

The reactance of capacitance. From an earlier experiment in this area we found that when an alternating current flows through a circuit including a condenser and a lamp connected in series the lamp glows, but when a direct current flows through the circuit the lamp does not light. The lamp glows in the first instance because the alternating current charges the plates of the conductor alternating positively and negatively 120 times per second. The alternating current formed in this manner flows through the lamp. The strength of the alternating current is directly proportional to the capacitance of the condenser. This current is opposed by the reactance of the condenser, and thus the lamp merely glows rather than shines brightly. The opposition set up by the condenser is known as the reactance of capacitance and is measured in ohms. No light appears when a direct current

HOW AN ALTERNATING CURRENT IS MEASURED

flows through the circuit because the current does not charge the plates of the condenser alternately.

ANSWER THESE QUESTIONS

1. How does the flow of electrons in an alternating current differ from the flow in a direct current?
2. What differences appear between an alternating and a direct current when they flow through a circuit including a condenser and a lamp?
3. What is meant by cycles? by frequency? by phase?
4. How is the resistance calculated when a direct current flows through a circuit including a condenser and a lamp? How is the resistance calculated when an alternating current flows through the circuit?
5. What is meant by reactance? How does it differ from impedance?
6. How does the reactance of capacitance arise in a circuit?

SOLVE THESE PROBLEMS

1. A voltmeter across a coil reads 700 volts, and the ammeter in series with it reads 2 amperes. What is the impedance?
2. What is the strength of the current through a coil having 20 ohms impedance when a voltmeter across its terminals reads 120 volts?
3. A current of 12 amperes is flowing through a circuit with a reactance of 8 ohms and a resistance of 6 ohms. What is the impedance and what is the voltage of the circuit?

AREA TWO

How Is an Alternating Current Measured?

When we attempt to measure the rate of flow of an alternating current, we are confronted with the problem of measuring a current that changes regularly. With each complete cycle the current rises from zero to maximum value and then falls to zero; then it reverses its direction and again rises to maximum value and falls to zero. These changes—rising, falling, and reversing—make the process of measuring somewhat complex. Let us now see how such measuring is accomplished.



Ewing Galloway

The electric iron uses an alternating current. Its convenience is best appreciated by those who have used other irons.

The relation between maximum and effective alternating current.

There are two relative values of current to consider in measuring an alternating current, the maximum value represented by the crest of the sine curve and the effective value represented by the heating effect of the current. The ratio between these values has been accurately determined, the rate of flow of the maximum value being 1.414 times that of the effective value and the voltage 1.414 times that of the effective voltage. Expressed in reverse, the rate of flow of the effective value is 0.707 times that of the maximum value and the voltage 0.707 times the maximum vol-

tage. This relation is of great importance to electrical engineers in building electrical machines. In an electric motor, they know that if the voltmeter reading is 220 volts they must provide insulation for 311 volts.

Effective alternating current has the same value as direct current. To test this, let us place two similar lamps L_1 and L_2 in similar electric currents, the first lamp connected with a 115-volt alternating current and the second with a 115-volt direct current as shown in Figure 289. When we turn the switches, the lamps light with the same brightness, indicating that the heating effects are the same. If we check the measuring instruments, we find that the ammeter

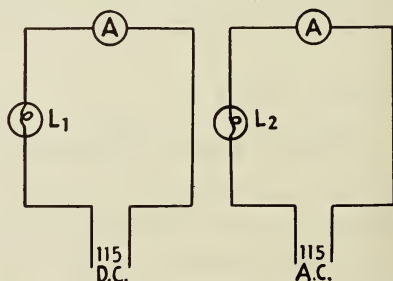


Fig. 289. Experiment for demonstrating equality of alternating and direct currents.

readings are the same in both circuits, and the voltmeter readings are the same. In the case of the alternating-current circuit, however, the readings measure the effective current. From this experiment we may define the effective-current ampere of an alternating current as the rate of flow through a given resistance that produces the same heat effect as an ampere of direct current. We may define the effective voltage as the voltage that causes one effective ampere to flow through one ohm of resistance.

Measuring instruments for alternating currents.

The ordinary ammeter and voltmeter such as we have already studied cannot be used in measuring alternating currents because the polarity changes with changes in direction in the circuit. The corresponding reverses in the magnetic field tend to turn the coil first in one direction and then in the other, but the inertia of the coil prevents it from turning rapidly and hence it merely flutters. Because of this condition special types of ammeters and voltmeters are used in measuring alternating currents.

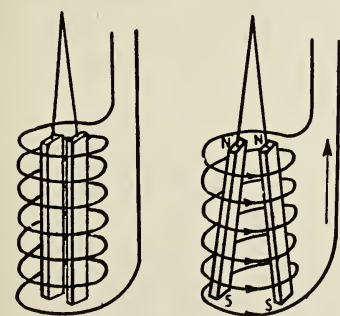


Fig. 290. Experiment with reaction of iron bars to alternating and direct currents flowing through a helix.

Repulsion type of ammeter and voltmeter. If two bars of soft iron are suspended in a helix, as shown at the left in Figure 290, and a direct current is sent through the helix, the bars become magnetized alike and repel



Ferdinand Hirsh

On the farm as in the city electricity performs important duties. This cream separator uses alternating current.

MODERN WORKERS AMONG ELECTRONS

each other, as shown in the drawing at the right. When the current is reversed, the bars again become magnetized alike and repel each other. Thus, regardless of the direction in which the

current flows, the bars react the same.

The reaction of these iron bars demonstrates the principle of the repulsion type of ammeters and voltmeters. These instruments come in varied forms, one of the most common forms of ammeter being that shown in Figure 291A. This device consists of a piece of soft iron attached to a helix and another piece of iron suspended close by. When an alternating current passes through the helix, the two pieces of iron become magnetized with the same polarity and the movable piece is repelled.

The repelling force is proportional to the current in the helix, and the pointer indicates the amount of the effective current. The voltmeter is constructed in the same manner except that a high-resistance coil is connected in series with the helix, as in Figure 291B, thus providing a high resistance.

The hot-wire ammeter. Another type of instrument used in measuring an alternating current is the hot-wire ammeter shown in Figure 292. This instrument contains a spring *S*, a small roller *R* attached to a pointer, and a thread *T* leading from the roller to span *AB* of an electrical circuit.

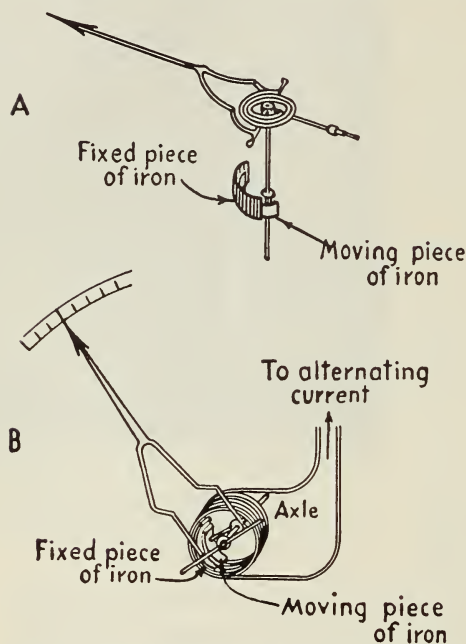


Fig. 291. Diagram showing the common forms of ammeters and voltmeters.

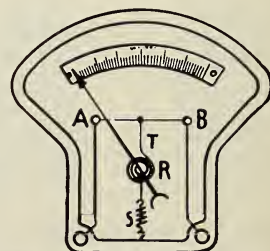


Fig. 292. Hot-wire ammeter.

HOW AN ALTERNATING CURRENT IS MEASURED

When a current passes through the circuit, the wire becomes heated and expands. The spring then pulls on the roller which turns the pointer on the dial, calibrated to show amperes. This ammeter is also used in measuring a direct current, since the heating effect is independent of changes in direction.

The wattmeter. An instrument used for measuring the power of an alternating current is the wattmeter. This instrument consists of two fixed coils, indicated by A and A_1 , connected with the circuit, and a movable coil B , connected by a system of levers with a pointer on a dial, as shown in Figure 293. When a current flows through the circuit, two magnetic fields are produced, one in the fixed coils proportional to the current and the other in the movable coil proportional to the voltage. Consequently, the movable coil tends to turn until its magnetic field is parallel to the magnetic field of the fixed coils. The turning is controlled by springs above and below the coils, indicated by C and C_1 . The dial is calibrated to show watts, and the reading is equal to the current times the potential difference, or volts times amperes. The wattmeter may also be used in measuring the power of a direct current, but such power is usually determined by finding the product of the ammeter and voltmeter readings.

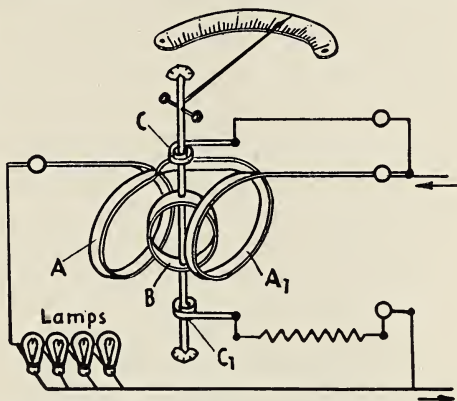


Fig. 293. The structure of an alternating-current wattmeter showing the coils and other essential parts.

The ratio of true power to apparent power. True power is the actual power used in an induction circuit in overcoming resistance. The wattmeter indicates this power, because it takes into account the difference in phase between the current of the circuit and the applied electromotive force. The product of the ammeter and voltmeter readings, which does not take into account the differ-

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ence in phase, is known as the apparent power. The ratio between the true power and the apparent power is known as the power factor. If we let I represent the ammeter reading, R the resistance of the circuit, and Z the impedance of the circuit, we may express the relationship as shown in the following equation:

$$\text{Power factor} = \frac{\text{true power}}{\text{apparent power}} = \frac{I^2 R}{I^2 Z} \text{ or } \frac{R}{Z}.$$

The power factor in the case of noninductive currents is one, but in the case of inductive currents it is always less than one. To find the power factor of an inductive current, such as an electromagnet, we divide the wattmeter reading, or true power, by the product of the ammeter and voltmeter readings.

ANSWER THESE QUESTIONS

1. What is meant by maximum current? What is meant by effective current? What is the relation between these currents?
2. Why is it impossible to use the ordinary ammeter and voltmeter to measure an alternating current?
3. What are the essential parts of a repulsion-type ammeter and voltmeter? How does the instrument work?
4. How does a hot-wire ammeter work?
5. What does a wattmeter measure? How is it constructed?
6. What is meant by true power? How does apparent power differ from true power?
7. What is meant by power factor? How is it determined?

SOLVE THESE PROBLEMS

1. Find the maximum current in a circuit when the ammeter indicates 5 amperes.
2. An ammeter shows that the A.C. passing through an electromagnet is 5 amperes. The voltmeter indicates a fall of potential of 50 volts. If the power factor is 0.85, what will a wattmeter indicate as the true power being consumed?
3. Find the impedance of the circuit in problem 2.
4. A current of 1 ampere flows through a coil of wire wound around an iron core, and the voltage across its terminal is 60 volts. A wattmeter properly connected reads 36 watts. What is the power factor? What is the impedance? What is the resistance? If 60 volts D.C. is applied to the coil, how much current will flow?

THE ALTERNATING-CURRENT GENERATOR

AREA THREE

How Does an Alternating-Current Generator Work?

When an armature rotates in a magnetic field, it produces an alternating current. Such a current may be transmitted directly to a circuit or it may be changed into a direct current by means of a commutator. Let us now consider further information about the work of an alternating-current dynamo, frequently known as an alternator.

Rotation of field or of armature. The small alternating-current generator, or alternator, is built with a rotating armature and a stationary magnetic field. A large alternator, on the other hand, is built with a rotating magnetic field and a stationary armature, as shown in Figure 294. In either case there is relative motion between the armature and the magnetic field, and the conductors in the armature cut across the lines of force in the field. The advantage of the stationary armature is that the current may be transmitted directly from the armature to the circuit without the help of brushes or slip rings for this purpose.

According to the drawing, the current in the conductors flows away from the reader when the north pole passes as indicated by the symbol $\oplus$. The current in the conductors flows toward the reader when the south pole passes as indicated by the symbol $\odot$. The current in each conductor therefore alternates with the passing of the poles, and every time both a north pole and a

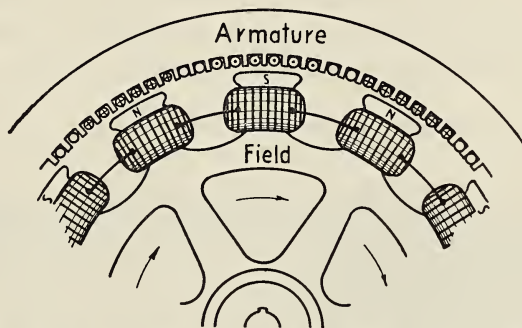


Fig. 294. Diagram of rotating field and stationary conductors in the armature, indicating directions of flow.

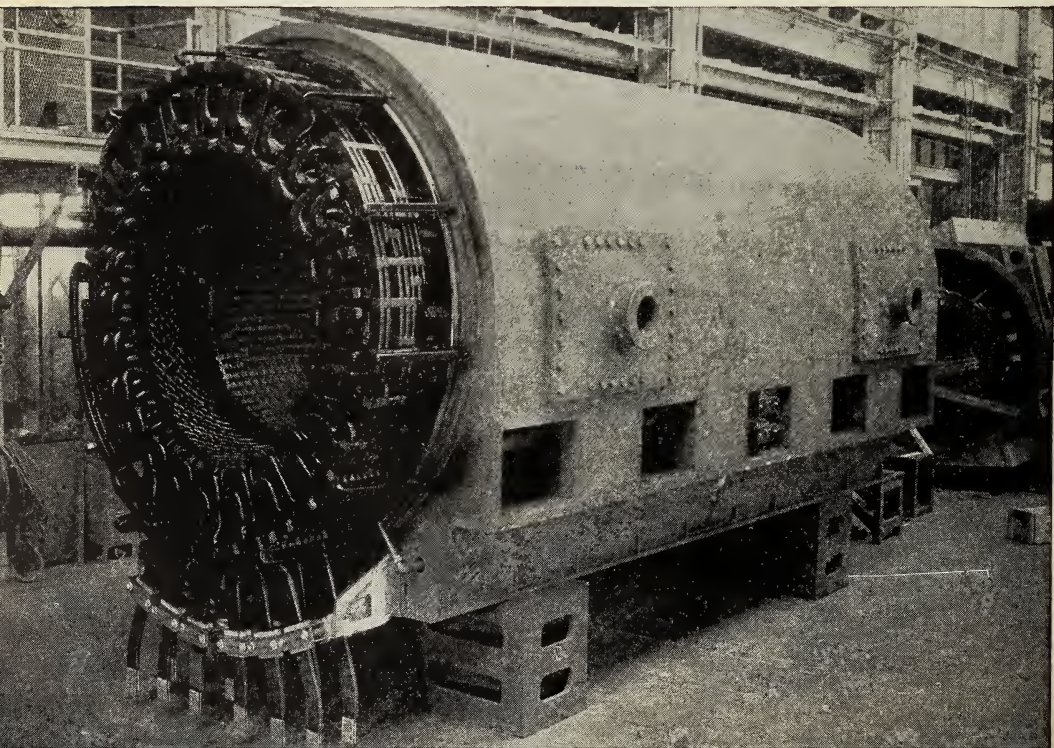
MODERN WORKERS AMONG ELECTRONS

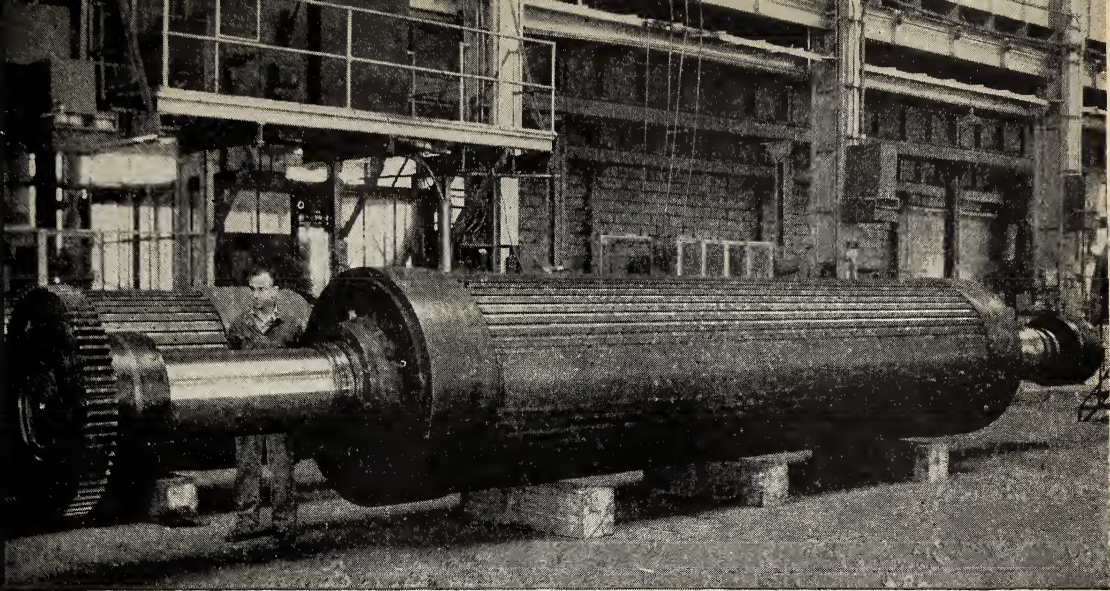
south pole pass a conductor a cycle is completed. If a dynamo has 12 poles in its magnetic field, 12 alternations are set up and 6 cycles are completed in each revolution.

The speed of a generator depends partially upon the number of poles in the field, for a field with a few poles must rotate faster than a field with many poles to generate the same current. To generate a 60-cycle current, for instance, a field with 12 poles must make 10 revolutions per second or 600 revolutions per minute, whereas a field with 2 poles must make 60 revolutions per second or 3600 revolutions per minute. In general, steam-driven generators operate at low rates of speed, from 75 to 150 revolutions per minute; water-driven generators operate at medium rates of speed, from 150 to 750 revolutions per minute; and turbines operate at high rates of speed, from 1800 to 3600 revolutions per minute.

Single-phase and polyphase dynamos. Alternating-current dynamos are classified as single-phase or polyphase dynamos, polyphase dynamos being two-phase or three-phase dynamos. A single-phase dynamo is one in which there is one coil in the

The huge mechanism pictured here is the stationary part of a large alternating-current generator. The moving part of this generator is illustrated on the following page.





This picture shows the large moving part of a steam-turbine generator. When the generator is in operation, it is driven at a rate of 1800 r.p.m. and creates 13,800 volts.

armature for each pole in the field. A two-phase dynamo is one in which there are two coils in the armature for each pole in the field. A three-phase dynamo is one in which there are three coils in the armature for each pole in the field. The coils in the two-phase dynamo are arranged in two sets; the coils of one set are placed between the coils of the other set and the coils in each set are arranged in series. The two sets of coils act the same as two armatures, and thus two currents are induced. These currents have the same frequency and voltage, but one current lags 90° behind the other as shown by the curves in Figure 295. Two sets of leads deliver the currents to the line.

A three-phase dynamo is constructed in the same manner as a two-phase dynamo except that there are three sets of coils in the armature, the coils of each set being connected in series. The three sets of coils act the same as three armatures, and thus

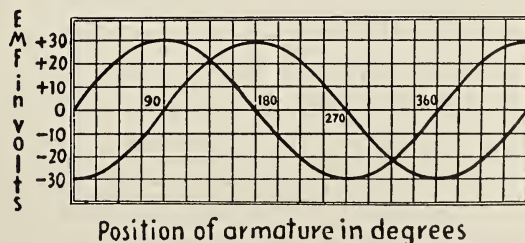


Fig. 295. Graphic diagram of currents set up when there are two armature coils for each pole in the field.

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three currents are induced. These currents, as in the case of the two-phase current, are alike in frequency and voltage but differ from the two-phase current in that each current lags 120° behind the preceding one. Since there are three armatures and three currents, there must also be three circuits. But three wires will provide for the three circuits if the wires are connected in such a manner that each acts as a return conductor for the other two outgoing circuits. The fields of all alternating-current generators are separately excited.

ANSWER THESE QUESTIONS

1. How are the armature and magnetic field arranged in small dynamos? How are they arranged in large dynamos?
2. What happens to the current in each conductor of the dynamo when a pole passes? How is a cycle completed?
3. What determines the speed of a dynamo? How fast do various types of dynamos operate?
4. What is a single-phase dynamo? a two-phase dynamo? a three-phase dynamo?
5. How are the coils arranged in two-phase dynamos and three-phase dynamos? What are the advantages of such dynamos?

AREA FOUR

How Do Motors Work on an Alternating Current?

The electric current in common use, such as the current that comes to the home, is an alternating current. This type of current is so generally used that we seldom give any thought to it when we purchase or use electric fans and other devices operated by motors. If the current in our homes, school, or office were not alternating current, however, we could not use the ordinary motors without also using a special device to make the current suitable to them. Generally the type of current for which motors are intended to be used is indicated on them.

MOTORS ON AN ALTERNATING CURRENT

The series-wound direct-current motor. To find out how a series-wound direct-current motor works on an alternating current, suppose we set up apparatus on the basis of the drawing shown in Figure 296. This apparatus consists of an electrical circuit including a six-volt direct-current motor connected in series and a bank of 32-candle-power carbon lamps used as a rheostat. When we turn on a 115-volt alternating current, the motor runs perfectly except for a certain amount of sparking at the brushes.

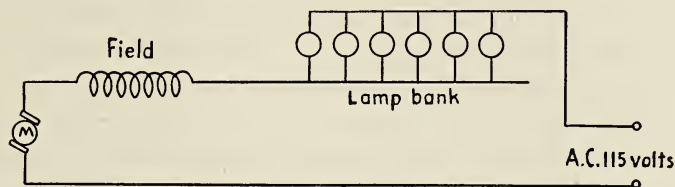


Fig. 296. Diagram showing the arrangement of apparatus for the experiment with alternating and direct currents.

From the foregoing experiment we conclude that a series-wound direct-current motor runs practically as well on an alternating current as on a direct current. The motor operates on the former current because the field and the armature are connected in series, and the alternation occurs in the field and the armature at the same instant. Thus the north poles in the field repel the north poles of the armature and the south poles repel the south poles, causing the armature to rotate just as it does on a direct current. When manufacturers make direct-current motors for use with alternating current, they laminate both the field cores and the armature cores to prevent sparking at the brushes. Some motors are labeled for use with either direct or alternating current.

Now let us return to our experiment and test a 6-volt shunt-wound motor in this circuit. In this case we find that the motor rotates scarcely at all, or only with a slow, jerky motion. This motor fails to operate satisfactorily on an alternating current because the current divides at the brushes into two currents, one passing through the field and the other through the armature. The field has many turns of fine wire and the armature only a

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few turns, and thus there is greater inductance in the field than in the armature. This difference in inductance causes the current in the field to lag behind that of the armature and alternation does not occur at the same instant.

The induction motor. The motor most widely used with an alternating current is the induction motor, which consists of a rotating part called the rotor and a stationary part called the stator. The rotor consists of an iron core made up of lengthwise copper bars attached to copper disks, such a core often being called a squirrel-cage rotor because of its appearance. The stator consists of pole pieces wound with coils, and the pole pieces are shaped to fit closely about the rotor. Large induction motors are usually of a two-phase type or a three-phase type and small motors of a single-phase type. Now let us see how these types of motors work.

The two-phase motor. The two-phase motor has four pole pieces and four coils, as indicated by any one of the drawings in Figure 297. Two coils are connected with one phase of an alternating current indicated by line 1, and the two other coils with the

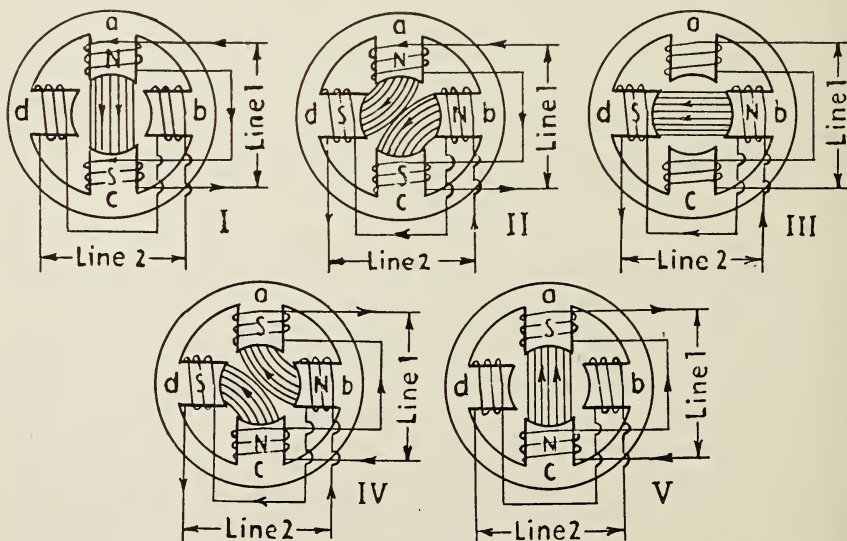


Fig. 297. Diagrams showing changing flow of current due to rotation of the field.

MOTORS ON AN ALTERNATING CURRENT

second phase of an alternating current indicated by line 2, the two phases differing by 90° . The pole pieces *a* and *c* are connected in series so that when *a* is a north pole *c* is a south pole and vice versa. Likewise, the pole pieces *b* and *d* are connected so that when *b* is a north pole *d* is a south pole and vice versa. The five drawings show conditions when the rotor turns to various positions in relation to the stator. The first drawing illustrates conditions when the current in line 1 is at maximum and the current in line 2 is at zero. Pole *a* in this case is a north pole, pole *c* is a south pole, and poles *b* and *d* are unmagnetized. The next drawing represents conditions 45 degrees later as indicated by the position of the rotor. Current one has decreased in value and current two has increased in value and all poles are equally magnetized. The third drawing represents conditions 45 degrees later, at which time pole *b* is a north pole, pole *d* is a south pole, and poles *a* and *c* are unmagnetized. In this instance, as we find by the change in the poles, the direction of the field has changed. What condition is represented by each of the other drawings?

The poles change in a clockwise direction around the stator and create a rotating magnetic field. If we suspend a small needle in the field, we find that it rotates, making one revolution for each revolution of the field. The rotor follows the rotating field but never goes as fast as the field. Were it to turn at the same rate of speed, it would cut no lines of force and no induced current or turning force would be produced.

Three-phase induction motor. The three-phase induction motor operates according to the same principle as the two-phase motor. The three-phase motor, like the two-phase motor, has a rotating magnetic field in the stator, and the rotor follows the field in the same manner and for the same reason. The difference between the two types of motors arises from the way in which the rotating field is produced. As was explained earlier, a three-phase current is produced by a generator with three sets of coils in the armature. Three currents are induced each in a different phase. The second current reaches its maximum 120° behind the first, and the third 120° behind the second.



As this student rotates the ring shown here, he transforms the current from the battery into alternating two-phase and three-phase currents. At the left of the picture are the stator and rotor parts of the induction motor used in a washing machine.

The single-phase motor. In the case of a single-phase motor, such as the small motors used around the home, the single phase does not produce a rotating field and the motor will not start. As a means of overcoming this difficulty, the current is divided and one branch is made to lag behind the other. Dividing the current in this manner is called splitting the phase and produces the same effect as a two-phase current. The stator of the washing-machine motor, for instance, consists of two sets of windings. The first, or running coils, are made up of turns of large wire and take the current directly from the line. The second, or starting coils, on the other hand, are made of fine wires and connected across the line. Since the inductance in the starting coils is much greater than the inductance in the running coils, the current in the former coils lags behind the current in the latter coils and causes the field to rotate. The lag serves to start the motor.

MOTORS ON AN ALTERNATING CURRENT

The watt-hour meter. The watt-hour meter in our homes is of the induction type. It has no commutator and no sliding contacts. The windings are stationary, and the moving part is a disk. It has two windings: a potential (voltage) coil of high resistance, connected across the line, and a current coil of low resistance, connected in the line. Figure 298 shows the construction. The currents in these two coils produce a rotating magnetic field similar to the rotating magnetic field of the two-phase induction motor described on page 636. This is because the potential coil has high inductance, producing a very great lag of current, whereas the current coil has very little inductance. The rotating magnetic field induces currents in the disk so that the disk rotates in the same manner as the rotor of an induction motor.

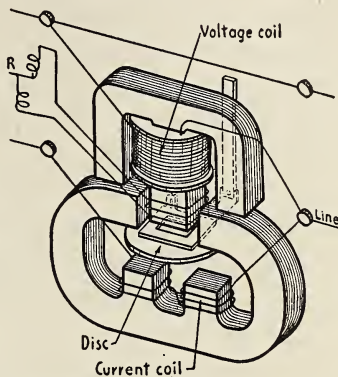


Fig. 298. Essential parts and wiring of a watt-hour meter.

The magnetic field of the potential coil is a measure of volts, and the magnetic field of the current coil is a measure of amperes. The turning force is proportional to the product of the two fields, or to the product of the volts times the amperes, which is equal to watts. The disk rotates between poles of a horseshoe magnet, which is not shown in the diagram but can be seen in your watt-hour meter. The disk acts as a brake or control, because of eddy current set up in it. A shaft is turned that operates a train of gears that indicate the number of kilowatt hours.

The synchronous motor of an airplane. The synchronous motor is merely an alternating-current generator used as a motor. Such a motor must be started as a generator and must run as a generator until it produces a current in the same phase as that in the circuit. Then it runs at constant speed unless overloaded.

The principle of the synchronous motor is widely used in the field of aviation. Self-synchronizing motors placed in different

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parts of the airplane transmit information to the pilot through dials on the instrument board. They enable him to know what is happening in the various parts of the airplane, as, for instance, the location of the wheels on his landing gear.

In order to secure this information two motors are used, one known as the transmitting motor and the other as the receiving motor. The transmitting motor is attached to a certain part of the airplane, such as one of the wheels. When the wheel changes its position, the rotor turns and changes the relative position of the rotor and the three-phase windings of the stator. Three induced currents are formed in the stator; the voltage of each depends upon the position of the rotor. Conductors lead from the stator to the receiving motor, with the connections so arranged that the three-phase windings of the stator of the receiving motor get the same voltage as the three-phase windings of the stator of the transmitting motor. Therefore the rotor of the receiving motor moves to the same relative position as that held by the rotor of the transmitting motor. The rotor of the receiving motor turns a pointer on a dial, the dial pointing up when the wheel of the landing gear is up and down when the wheel is down. The other synchronizing motors operate in the same manner.

The dynamotor used in an airplane. The dynamotor is also known as a rotary converter or as a synchronous converter, since it can be used for changing alternating current to direct current, or when reversed for changing direct current to alternating. The device is used in airplanes to provide A.C. for self-synchronizing motors. It differs somewhat from the motor-generator assembly discussed later in this unit. The dynamotor is a machine with one field and an armature with a commutator and slip rings. When it is used to change A.C. to D.C., the current is applied through the slip ring and D.C. is taken from the commutator. When the power is supplied from a D.C. source, as for use in the self-synchronizing motor, it enters through the commutator and A.C. is taken from the slip rings. We learned in our study of the D.C. motor that in its revolving armature a back e.m.f. is set up which

MOTORS ON AN ALTERNATING CURRENT

opposes the line voltage. In the dynamotor this back e.m.f., which is alternating, is led to slip rings and taken off as an alternating current. As the line current and induced current oppose, very little current flows in the armature and the power loss is small.

The armature of a dynamotor may have only one set of windings connected to a commutator at one side and is tapped by leads to the slip rings at the other side. Many synchronous converters are so constructed. In some dynamotors there are two separate circuits on the armature: one consisting of coils of comparatively few turns connected to the commutator, the other consisting of a circuit that has many turns to increase the voltage and that, for A.C. current, may be taken from the slip rings. Dynamotors are so used in airplanes as to change D.C. to A.C. in order to get the A.C. current that is necessary for the self-synchronizing motors used for remote reading of many instruments.

ANSWER THESE QUESTIONS

1. Why does a series-wound direct-current motor operate on an alternating current? Why does a shunt-wound direct-current motor not operate on an alternating current?
2. What is meant by an induction motor? Upon what principle does it operate?
3. How does a two-phase induction motor differ from a three-phase induction motor?
4. What is a watt-hour meter? How does such a meter operate?
5. How does the synchronous motor of an airplane help the pilot to determine various conditions about an airplane?
6. What purpose does a dynamotor serve in an airplane?

SOLVE THESE PROBLEMS

1. What will be the horsepower output of a single-phase motor when it is using 10 amperes on a 220-volt A.C. line, if the power factor is 0.84 and the efficiency is 80 per cent? Find the true input power, and from that the output power.
2. What will be the full-load current of a single-phase induction motor of 10-HP. rating on a 220-volt line, if its power factor at full load is 80 per cent, or 0.80, and its efficiency is 85 per cent? Find true input power and then apparent power.

AREA FIVE

How Do Transformers Make Electric Power Available?

Alternating current is used far more extensively than direct current because it can be generated and distributed more economically. One reason why electricity has become so widely used is the fact that it is relatively inexpensive. Its use is possible, however, because of a device known as the transformer.

How transformers are made. Let us examine a bell-ringing transformer. There are different types, but those similar to the drawing in Figure 299 are in general use. Every transformer has two separate coils wound on a common iron core. This iron core

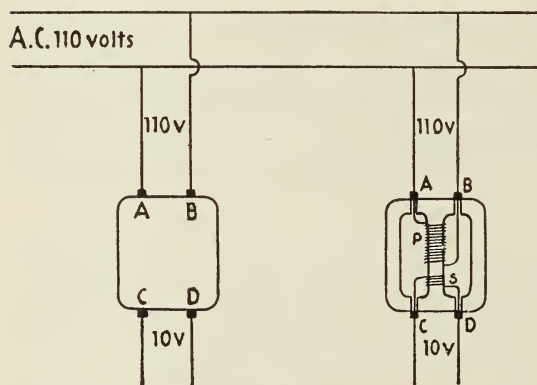


Fig. 299. Parts and wiring of a bell-ringing transformer.

forms a continuous magnetic circuit, or closed core. One of the coils has many turns of fine wire; the other, a few turns of heavy wire. One coil is connected to the main line and is called the primary; the other is the secondary. If the coil of many turns is the primary, the transformer is known as a

step-down transformer. The bell-ringing transformer and the transformer that furnishes the current for homes are step-down transformers. If the coil of few turns is primary it is a step-up transformer such as is used at electric power plants.

Types of transformers. Transformers are of two general types: the core type, in which the two coils are wound around two sides

TRANSFORMERS AND ELECTRIC POWER

of a rectangular iron core, as shown in the drawing at the left in Figure 300, and the shell type, shown in the center drawing in Figure 300, in which the iron core is built around the coils. In

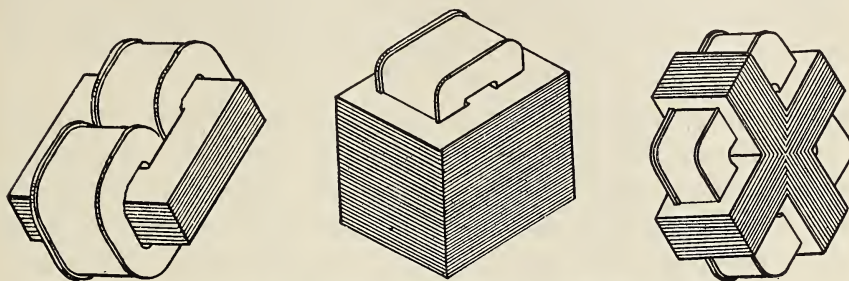


Fig. 300. Transformers of the core type and the shell type.

both these types the cores are built up of thin sheets of annealed silicon steel. Another type, shown in the drawing at the right in Figure 300, is a modification of the core type. The windings are on one leg, and the other leg is divided into four parts placed around the center leg, upon which the coils are wound.

Principle of the transformer. In Figure 301 a transformer is shown with the two coils on different legs of the rectangular iron core. The primary has many turns and the secondary few turns. Since transformers are always used on alternating current, the current in the primary is always changing. The changing field set up in the core cuts the turns of the primary and sets up in it an e.m.f. of self-induction that nearly equals the voltage of the line. The flux passes through the secondary coil as well as through the primary; when it reverses and changes in one coil, it reverses and changes in the other coil also. Hence an e.m.f. is set up in the secondary. Since the number of lines of force cut per turn in the secondary is the same as in the

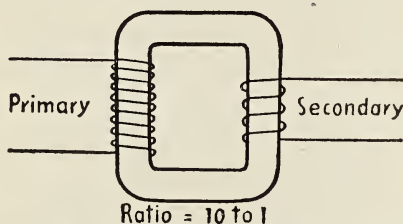


Fig. 301. Simplified drawing of a transformer, showing its essential features.

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primary, the induced voltage per turn in the secondary is the same as in the primary. Thus if there are twenty turns in the secondary to one in the primary, the voltage in the secondary will be twenty times the line voltage. This means that, if the primary terminals are connected to a 115-volt A.C. line, the voltage at the terminals of the secondary will be 2300 volts.

Low voltage from high. In a step-down transformer there are more turns in the primary than in the secondary. The transformer used to step down the voltage for house use has twenty turns in the primary to one in the secondary. Hence the voltage is stepped down from 2300 to 115 volts. Figure 302 shows

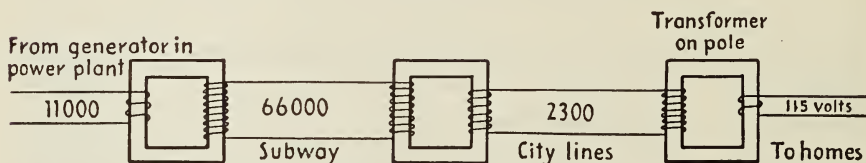


Fig. 302. Simplified drawing illustrating operation of step-up and step-down transformers.

both step-up and step-down transformers. The relation of voltage and turns may be stated thus: The voltage in the primary coil is to the voltage in the secondary as the number of turns in the primary is to the number in the secondary. The following equation expresses this relation:

$$\frac{\text{Voltage in primary}}{\text{Voltage in secondary}} = \frac{\text{turns in primary}}{\text{turns in secondary}}$$

Relation of primary and secondary current in a transformer. What effect has this multiplying or dividing of the applied voltage by a transformer on the power it delivers? It has very little effect, because the power delivered is practically the same as the power applied to it. A very little power, from 2 per cent to 5 per cent, is lost in the form of heat in the transformer. When the voltage is stepped up the amperage is reduced, and consequently the power loss, or i^2r , becomes small. The voltage of the secondary

TRANSFORMERS AND ELECTRIC POWER

is twenty times as great as the voltage of the primary, and the current in the secondary is one-twentieth as great as the current in the primary. The power given out is secondary voltage multiplied by secondary current. This is approximately equal to the primary voltage multiplied by the primary current. The following equation shows this relationship:

$$\frac{\text{Primary amperes}}{\text{Secondary amperes}} = \frac{\text{secondary volts}}{\text{primary volts}}.$$

Example. If a step-down transformer changes 2300 volts in the primary to 115 volts in the secondary and delivers 10 amperes to the house, what current is drawn from the main line?

$$\frac{\text{Primary amperes}}{10} = \frac{115}{2300}.$$

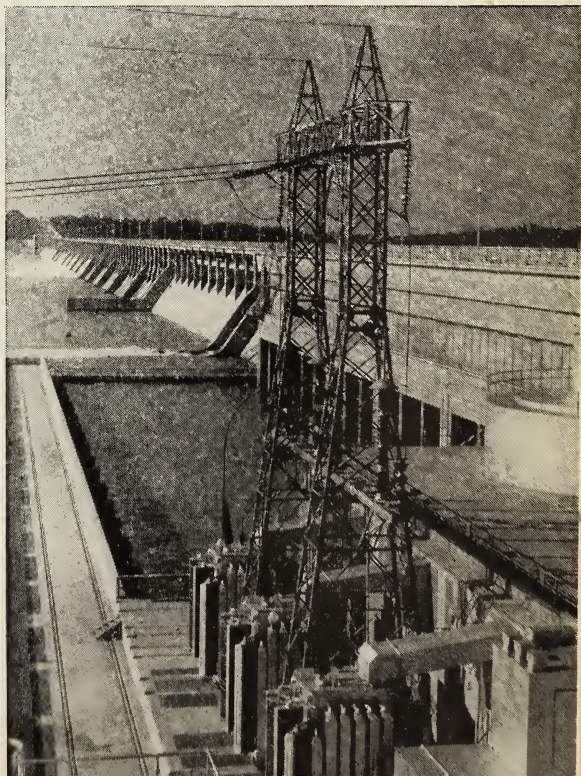
$$\text{Primary amperes} = \frac{1}{2} \text{ ampere.}$$

Current in the primary when there is no current in the secondary.

The primary coils are always connected across the main line. Is there a current in the primary coils when no current is drawn from the secondary? The answer to this question is clear if we remember what we have learned about self-induction in an earlier unit. An e.m.f. of self-induction is produced in the primary coil by the alternating P.D. of the main lines, which hold back the current. As the induced e.m.f. is nearly equal to the line voltage, there is practically no current flowing in the primary coil when there is no current in the secondary. When a current is drawn from the secondary, this current flowing in the secondary sets up a field of its own,

Before being carried to distant cities, the electric current passes through gigantic transformers at a hydroelectric plant.

Ferdinand Hirsch



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which tends to neutralize the primary field and decrease its self-induction. This allows the impressed voltage to send more current in the primary. Therefore the greater the current in the secondary, the greater the current in the primary. In this way the transformer is complying with the law of conservation of energy. The transformer makes possible the wide use of electric power because it aids in the economical transmission of electrical energy from great central power plants to points where it is to be used.

High voltage and low power loss. In order that electrical energy may be supplied at reasonable cost, it must be produced at low cost, and it must also be distributed with small losses on the lines. Energy is lost in the form of heat as the current is pushed through the wires against resistance. This heat loss is proportional to the square of the current in amperes and to the resistance of the circuit. Power is equal to volts multiplied by amperes. A step-up transformer raises the voltage and lowers the amperes, delivering power at a high voltage and a low amperage.

The following example shows the economy of making use of high voltage in transmitting power. If 115,000 watts of power is to be sent over a line whose resistance is 10 ohms, what is the line loss at 2300 volts and at 11,500 volts? $\text{Current} = \text{power} \div \text{volts}$. At 2300 volts the current $= 115,000 \div 2300 = 50$ amperes. Power loss $= I^2 R = 50^2 \times 10 = 25,000$ watts. At 11,500 volts the current $= 115,000 \div 11,500 = 10$ amperes. Power loss $= 10^2 \times 10 = 1000$ watts power loss. The loss in the second case is one twenty-fifth of the loss in the first.

Other uses for transformers. Step-down transformers are used to supply heavy currents at low voltage for welding. We may illustrate this by winding one or two turns of very heavy copper wire around the core of a step-down transformer and connecting the primary to a 110-volt A.C. circuit. If the terminals of the large wire are two iron nails, and if the ends of the nails are brought together so that they are just touching, they get red

TRANSFORMERS AND ELECTRIC POWER

hot and can be welded. Transformers are used in measuring high voltages and strong currents. Step-down transformers are used for voltmeters to lower the voltage, and step-up transformers for ammeters to step up the voltage.

What the transformer does not do. The transformer does not change an alternating current to a direct current nor does it change the frequency of a current. The frequency of the secondary current is always the same as the frequency of the primary current. Except for a small loss, the transformer does not change the power.

What is a rectifier? Although alternating current is more widely used than direct current, there are certain purposes for which the direct current is better and even necessary. Thus direct current is better for running streetcars and necessary for charging storage batteries. Whenever direct current is needed and only alternating current is available in a circuit, the alternating current must be changed to a direct current. One of the chief devices for this purpose is the motor generator, and other devices for the purpose are various types of rectifiers hereinafter described.

The motor generator. The motor generator, as the name indicates, consists of an alternating-current motor and a direct-current generator. The alternating current from the line runs the alternating-current motor which in turn runs the direct-current generator. The generator provides direct current for the purposes desired.

The vacuum-tube rectifier. The vacuum tube rectifier, Figure 303, is an evacuated tube containing an inert gas at a low pressure, usually three to eight millimeters of mercury. In the tube are a carbon electrode *A* and a tungsten filament *F*. The filament emits electrons. The carbon

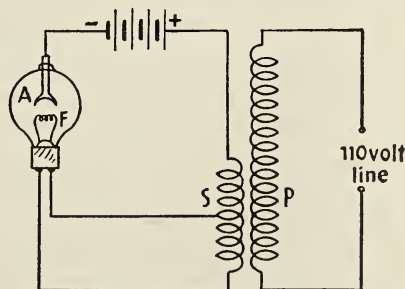


Fig. 303. Diagram of a vacuum-tube rectifier.

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electrode is connected to one side of the secondary coil and the filament to the other. When the carbon electrode is positive, electrons are attracted from the filament and ionize the gas, making it a conductor, and current passes through the tube. But during the half-cycle in which *A* is negative no electrons are captured by it. Thus the current of electrons passes from the filament to the carbon during the half-cycle in which *A* is positive. The statement is usually made that the positive current flows from the carbon to the filament. We have a pulsating direct current that can be used in charging storage batteries.

The electrolytic rectifier. A rectifier can be made by immersion of lead and aluminum plates in a suitable electrolyte such as a solution of ammonium phosphate, ammonium carbonate, or

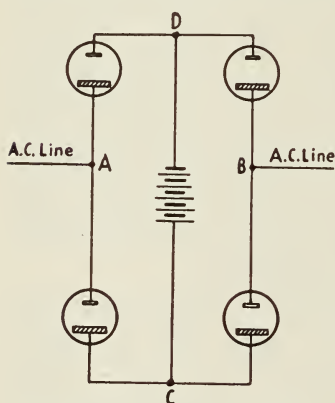


Fig. 304. Diagram of a simple electrolytic rectifier.

sodium carbonate in four cells. When connected as shown in Figure 304, the current will enter each cell only by the aluminum plate and leave by the lead plate. An alternating current entering at either *A* or *B* leaves the rectifier at *C*. Since both alternations leave the cells at *C*, a direct current flows from *C* to *D* through the storage battery. Although this type of rectifier is comparatively cheap and can be easily made, it is not very efficient and heats up rapidly.

ANSWER THESE QUESTIONS

1. What work does a transformer do and how does it do this work? Make a diagram of the transformer that is used in your home.
2. Why does a step-up transformer raise the voltage? Draw a diagram of a step-up transformer.
3. How does the transformer make electrical energy cheap enough for common consumption?
4. Why is the use of a transformer on a D.C. circuit not possible?
5. Why is the iron core of a transformer made up of thin sheets?
6. How are adjoining rails of a streetcar line often welded?

SUMMARY

7. How do the rectifiers used in a battery service station change alternating current to direct current to charge a storage battery?
8. How is the rectifying tube in your radio made?

SOLVE THESE PROBLEMS

1. The feed lines on the poles near your home carry 2300 volts. What is the ratio of the number of turns in the primary and secondary of the transformer on the pole if the wires entering your home carry 115 volts? if the secondary lead-out wires are to carry 230 volts?

2. An A.C. generator develops 11,000 volts for transmission. It is desirable to raise this to 66,000 volts. If the number of turns in the primary is 100, what is the number required in the secondary?

3. A bell-ringing transformer has 800 turns in the primary and 80 turns in the secondary. How many volts does the bell circuit get when the primary is connected to the 115-volt home electrical circuit?

4. A current of 6 amperes at 110 volts enters a transformer, and a current of 0.58 ampere and 1100 volts leaves the transformer. What is the efficiency of the transformer?

SUMMARY

Alternating currents occur when there is relative motion of a conductor and a magnetic field. Direct currents occur when this alternating current is changed by a commutator. Nearly all electrical energy used comes from alternating currents because that way is the more economical. There are two reasons for this economy: An alternating-current generator can induce much higher voltages than a direct-current generator, and power from alternating current can be transmitted more economically because it can be transmitted to high voltage and low amperage. Alternating and direct current have the same heating effect. Alternating current cannot be used for chemical action. The important difference between alternating and direct current is in the magnetic effects. Direct currents in electromagnets are opposed only by resistance. Alternating currents are opposed by resistance and by back e.m.f. induced by the changing circuit, which also opposes the current. The opposition due to inductance

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is called inductive reactance. Impedance is not the sum of resistance and reactance, but is the square root of the sum of their squares.

$$\text{Impedance} = \sqrt{(\text{Resistance})^2 + (\text{Reactance})^2}.$$

Ohm's law for an inductive circuit is: Current = impressed voltage divided by impedance. $\text{Current} = \frac{\text{e.m.f.}}{\text{impedance}}.$

Direct currents will not flow in a circuit that includes a condenser. Alternating current will flow, but an opposition is added called the reactance of capacitance.

In the measuring of alternating currents their effective value is taken. The effective value is 0.707 times the maximum value. An A.C. ammeter measures the effective value of the current. An A.C. voltmeter is an ammeter of high resistance that measures the effective voltage. A wattmeter measures true power. The true power in an inductive circuit cannot be found by the use of a voltmeter and an ammeter, as D.C. power is found. True power = volts $\times$ amperes $\times$ the power factor. The power factor is the ratio of true power to apparent power, or volts $\times$ amperes. It is also equal to the ratio of the resistance to the impedance.

Small alternators are like D.C. generators except that the current is taken off by slip rings, and the field is excited by direct current from some outside source. Large alternators generally have revolving fields and stationary armatures. The armatures are wound in three sets of coils so placed that the revolving field induces three different currents differing in phase by 120°. These currents are carried in the line by three wires as a three-phase current. Alternating-current motors are of three types: series, induction, and synchronous motors. Series motors are like series D.C. motors. Induction motors in large sizes are run by three-phase current, and small induction motors, such as are used in homes, are run on single-phase current. They have a stator in which is set up a rotating field, and a rotor in which a current that causes it to rotate is induced. The synchronous motor is an alternator which may be used as a motor.

SUMMARY

A transformer consists of two coils on a common iron core. One coil has a few turns of heavy wire, the other many turns of fine wire. In a step-up transformer the coil of few turns is in the main circuit. The coil in the main circuit is the primary, the coil carrying the induced current is the secondary.

$$\frac{\text{Voltage in secondary}}{\text{Voltage in primary}} = \frac{\text{turns in secondary}}{\text{turns in primary}}$$

The power is the same in both primary and secondary coils.

$$\frac{\text{Voltage in secondary}}{\text{Voltage in primary}} = \frac{\text{current in primary}}{\text{current in secondary}}$$

Alternating currents may be converted to direct currents by motor generators and by various types of rectifiers.

Why, applying Fleming's rule, is the current in an armature always alternating?

What is the difference in the movement of electrons in direct and alternating current?

Why does alternating current make electricity so cheap that people can afford to use it?

What is a choke coil? What is the relation of inductive reactance to a choke coil?

Why is the impedance in an inductive circuit not the sum of the resistance and the reactance?

Why is the rate of an alternating current impossible to measure directly?

How does the watt-hour meter in your home measure the amount of electrical energy you have used?

Why will a 110-volt A.C. motor burn out if connected with a 110-volt D.C. circuit?

Why will the motor on your vacuum cleaner run on either alternating current or direct current?

What type of motor is in your electric clock?

How does the transformer on the pole near your home make possible a source of cheap electrical energy for your home?

Why does an alternator have a small D.C. generator?

Except for a little power loss in the wires of a transformer, the power in the secondary is equal to the power in the primary. How can this be shown to be true from the relation of voltages and amperages in the coils of a transformer?

MODERN WORKERS AMONG ELECTRONS

SOLVE THESE PROBLEMS

1. How much current will flow through an electromagnet, the impedance of which is 25 ohms, on a 115-volt circuit?
2. How much impedance is in a coil, the resistance of which is 6 ohms, with a reactance of 8 ohms?
3. On a 110-volt A.C. line 5.5 amperes flow through an electromagnet, the resistance of which is 12 ohms. What is the impedance? What is the reactance?
4. What is the power factor of a coil when 80 volts causes 5 amperes to flow through it and the wattmeter reads 360 watts?
5. To what voltage in the secondary will a step-down transformer with 50 turns in the primary and 5 in the secondary reduce 110 volts in the primary?

INVESTIGATIONS

1. How are inductance reactance of coils and the capacitance reactance of condensers used in radio aeri-als?
2. Visit some electric power plant. Note whether the alternators have a rotating armature or a rotating field. Has the armature one set of windings or three sets? If the armature is stationary, notice how the three sets of coils are placed in the armature.
3. Procure the motor from an old vacuum cleaner and examine the armature and field. Explain how it will run on alternating current.
4. Procure the motor from an old washing machine. Note the structure of the rotor. Is there any electrical connection between stator and rotor? Note the coils in the stator, and tell why some of the coils are connected through the automatic switch. Why are these coils necessary for starting and not needed after the rotor has started?
5. Procure a small transformer used for ringing the bell on a toy electric railroad. Notice the turns in primary and the turns in secondary. The resistance of the primary of such a transformer is rather small; why does it not cause a short circuit when put across a 115-volt line?
6. Construct an electrolytic rectifier using aluminum plates, lead plates, and baking soda.



The Indian huntsman shown here had to look out over great distances as he sought his prey. Today modern optical instruments enable us to see many times as far as this Indian could see.

Exploring the Universe of Light Energy

LIGHT AND VISION

In early times man was chiefly an outdoor individual. His life activities consisted largely of hunting and fishing, and he used his eyes to detect moving objects at great distances in order to find his prey, or to spy out the approach of an enemy in the surrounding landscape. He rarely needed to use his eyes for close work or for looking at objects after dark.

UNIT
ELEVEN

EXPLORING THE UNIVERSE OF LIGHT ENERGY

Today man uses his eyes in a very different manner. Instead of depending upon long-range vision, he depends chiefly upon close-range vision. People are reading and writing in offices and homes; they are applying themselves closely to machines in factories and laboratories; and they carry on many activities at night. Thus they subject their eyes to a great variety of conditions, such as working in well-lighted offices, walking along dimly or well-lighted streets, driving automobiles by night or by day, and attending motion-picture shows.

To enable people to have the proper amount of light for all these activities, scientists have made a special study of light. From this study they have found more efficient ways of lighting buildings by day or night by providing greater window space and suitable forms of illumination. By using the principles of reflection or the turning back of light when it strikes an object, and refraction or the bending of light when it passes from one medium to another, they have constructed many practical devices. Among these devices are ordinary eyeglasses that enable persons with defective vision to use their eyes without strain and fatigue. Other devices are telescopes that enable astronomers to study heavenly bodies, and microscopes that enable biologists to study the world of plants and animals. From the scientific study of light also have come motion pictures, pictures transmitted by wire, and television.

Understanding of the nature and behavior of light has been greatly increased since the beginning of the twentieth century. At the same time, of course, more has been learned about the behavior of energy in general, because light is a manifestation of energy. The recent findings concerning the transmission of light have added a great deal to our knowledge of the physical universe. Advances have been made in analyzing the nature of light and also in using our knowledge to promote human welfare. This unit will help you to understand the most important facts about the nature of light and some of the principles related to its use. More specifically, you will consider the topics indicated by the questions on the following page.

AREAS OF STUDY

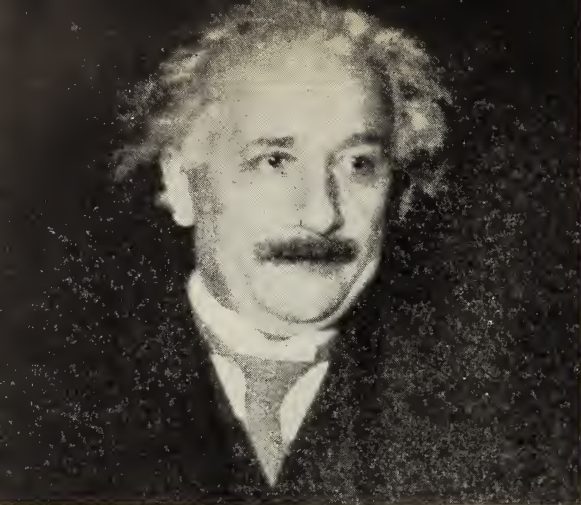
1. *What is light?*
2. *How are speed and intensity of light measured?*
3. *What are the principles of reflection of light waves?*
4. *What are the principles of refraction of light waves?*
5. *How are the principles of the lens illustrated in vision and in optical instruments?*
6. *How are colors produced?*

AREA ONE

What Is Light?

The great source of light in the world is the sun, which gives us the light known as natural light or daylight. Besides depending upon the sun for light, man has learned to produce light through the transfer of energy. Such light, known as artificial light, lacks some of the characteristics of natural light but is widely used in the absence or insufficiency of natural light. To lay a foundation for the study of light, let us first consider briefly some of the theories which seek to explain the nature of light.

Theories regarding light. The first person to propose a reasonable theory of light was Sir Isaac Newton, who, early in the seventeenth century, advanced the corpuscular theory. According to this theory light is made up of very fine particles, or corpuscles, that are projected from the source through space at an enormous velocity. This theory was widely accepted for more than a century, partly because of Newton's great reputation as a scientist. The second person to propose a reasonable theory of light was a Dutch scientist named Christian Huygens, who later in the



Albert Einstein
(1879-)

Einstein was born in Germany and received his education in Switzerland. He began to support himself at an early age by teaching mathematics and physics. In 1905 he published his first work on the theory of relativity, and later made known his "light-quantum" theory and the law of the photoelectric effect. Einstein's accomplishments mark him as one of the great scientists of our time.

Century Photos, Inc.

seventeenth century advanced the wave theory of light. According to this theory, light is a form of wave motion that is transmitted from a source through space. This theory for a time attracted little attention, but near the beginning of the nineteenth century it became widely accepted and has continued in favor until recent years.

One of the difficulties that scientists have encountered in explaining the wave theory is the difficulty of finding a plausible description of the medium known as ether. If ether serves as a conductor of light, it is found wherever light is found, penetrating on the one hand the expanses of the universe and on the other hand the intermolecular spaces in our environment. Just what ether is, if it exists, scientists have been unable to discover, and therefore they accept the wave theory with certain reservations. There are many indications that some sort of wave motion is responsible for the transmission of light.

Investigations within the present century have led scientists to question seriously the existence of the elusive ether medium. One of the modern theories, known as the quantum theory and advanced by Max Planck about 1912, suggests that light travels through space in small pockets of energy known as quanta. Another theory, known as the theory of relativity and advanced somewhat later by Albert Einstein, also raised some doubts about

the existence of the ether. Both these theories revert somewhat to the corpuscular theory, but at the same time admit certain phases of the wave theory.

The new theories of light have given scientists a more satisfactory understanding of the behavior and transmission of light. However, for practical purposes we shall consider light as a form of energy transmitted by waves through the indefinable medium known as ether. Such a discussion will enable us to analyze the behavior of light adequately, even though we may be somewhat undecided as to what light is and exactly how it travels.

Indications of waves. To test the behavior of light, suppose that we bind together with rubber bands two pieces of plate glass, two centimeters wide and 10 centimeters long. After we have bound the pieces securely, we pry them apart at one end and insert a small piece of paper to form a thin wedge of air between the plates. The arrangement of the plates should be similar to PM and PN in Figure 305, in which the plates are spread widely to show the transmission of waves. To complete our apparatus, we soak a piece of asbestos or drawing paper in salt water and place it over the tube of a Bunsen burner to secure a yellow light.

The dotted lines represent the reflected waves from PM and the solid lines the reflected rays from PN . When the distance between the reflecting surfaces is such that the two reflected waves are out of phase, as at ab , the waves interfere and produce a dark band. For the next dark band the distance between the reflecting surfaces must be one-half wave length greater, as at ef . When the distance between the reflecting surfaces is such that the two

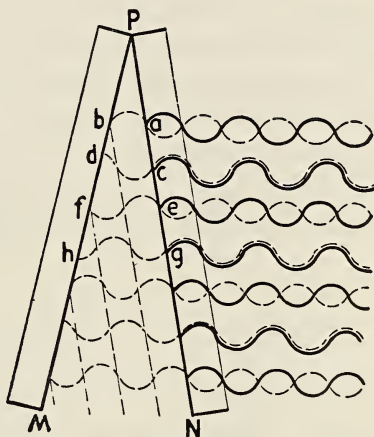


Fig. 305. Arrangement of glass plates for experiment with light waves.

EXPLORING THE UNIVERSE OF LIGHT ENERGY

reflected waves are in phase, as at *cd*, the waves reinforce each other and produce a yellow band. For the next yellow band the distance between the reflecting surfaces must be one-half wave length greater, as at *gh*.

Thus the action of light waves is similar to the action of sound waves. When experimenting with sound waves, we found that silence occurred when the waves were out of phase by one-half wave length, and that sound was intensified when the waves were in phase. In the present experiment with light waves, black bands appeared when the waves were out of phase, and the colored bands were intensified when the waves were in phase.

Light waves always transverse. We have learned that all wave motion is either longitudinal or transverse. Sound waves move to and fro in a longitudinal direction as is demonstrated when a portion of a coiled spring is compressed and then suddenly released. Light waves, on the other hand, move in a transverse direction as when a wire is plucked at right angles to its length. To understand this movement of light waves, let us pass a wire through one of the openings in each of two gratings placed with the slits parallel to one another as shown in the upper drawing in Figure 306. If we pluck the wire at right angles to its length, we produce a transverse wave that passes through the slits be-

cause there is nothing to interfere with its progress. If we turn one of the gratings, however, so that the slits are perpendicular to those of the other grating, as shown in the lower drawing, and pluck the wire as before, the wave is stopped by the horizontal slit. Now let us perform a similar experiment using the longitudinal waves of the spring. These waves pass

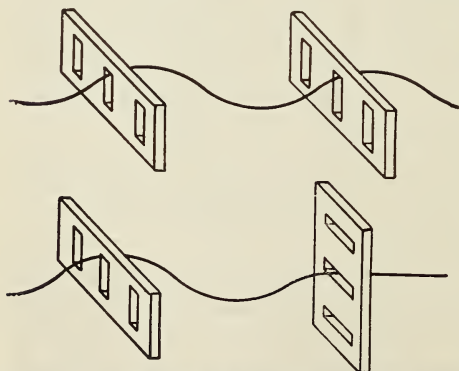


Fig. 306. The transverse motion of waves is one of the characteristics of light waves.

through both the vertical and longitudinal gratings without interference. Finally let us apply our findings to two tourmaline crystals which behave in the same manner with reference to light waves as the gratings do to the springs. Light passes through the first crystal but loses some of its intensity because only the waves of light pass through whose vibrations are in the same plane as the axis of the crystal. Light also passes through the second crystal if its axis is in the same plane. If the crystal is turned, however, so that its axis is at right angles to that of the first crystal, all light is stopped. This observation shows that light waves are transverse, for if they were longitudinal there would be no interference.

What is polarized light? When all the vibrations of light waves are stopped except those in the same plane, the light is said to be polarized. A convenient device for studying polarized light is a set of tourmaline tongs, shown at the left in Figure 307. Another device that operates on the same principle is a set of polaroid tongs. The disks in this device consist of cellulosic sheets in which



Fig. 307. The left-hand diagram shows tourmaline tongs. At the right are shown overlapping polaroid disks as used in polaroid tongs.

are embedded very minute needle-like crystals parallel to one another, the sheets being mounted between glass plates. When the disks overlap, as shown in the drawing at the right, the light rays are stopped in the region of overlapping.

Polarized light is of much value in everyday life. Mineralogists employ polarized light in microscopes to detect certain minerals, and engineers use polarized light in studying the models of airplanes to determine various stresses and strains. Automobile manufacturers are experimenting with polarized light to

EXPLORING THE UNIVERSE OF LIGHT ENERGY

protect the driver from the glare of headlights. In this instance the windshield and headlights are equipped with polarized glass which has qualities similar to those of the tourmaline crystals. The problem in developing the system is to provide the driver with sufficient illumination for his own car while protecting him from the headlights of approaching cars.

How are shadows produced? A shadow is a region of partial darkness caused by an object interfering with the passage of light. The shadow occurs because the rays of light travel in straight lines through the same medium and thus cannot bend around objects that lie in their path.

The upper drawing in Figure 308 shows a shadow, known as an umbra, caused by the interruption of light from a point. The umbra is larger than the object that interrupts the passage of light. The lower drawing shows a shadow caused by the interruption of light from a larger source such as a candle. In this instance a less intense shadow, known as the penumbra, appears

around the umbra, covering a region that receives part of the light. The larger the source of light in relation to the object that causes the shadow, the smaller the umbra.

Shadows explain the interesting phenomenon in the universe that we call an eclipse of the moon, in which the moon revolving around the earth passes into the shadow or umbra cast by the earth. In an eclipse

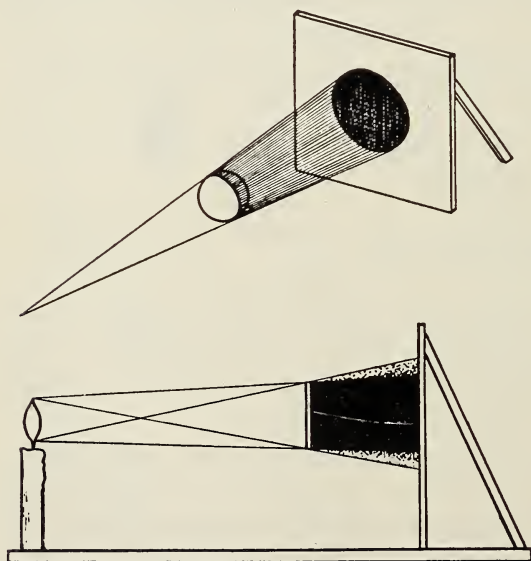


Fig. 308. Diagrams showing how shadows of various depths are cast on a screen by lights of different sizes.

WHAT LIGHT IS

of the sun the moon passes between the earth and the sun and casts an umbra upon the earth. Wherever the umbra strikes the earth, the eclipse is said to be a total eclipse, for it shuts off the sun entirely. On the outer fringes of the umbra, in the region of the penumbra, the eclipse is called a partial eclipse because only part of the light is cut off.

Definitions related to light. In order to understand different phases of light that we shall study later, let us consider the meaning of certain terms related to light. A luminous body is one that is visible because it emits light, as the sun or an electric light. An illuminated body is one that is visible because it reflects light, as the moon reflecting light from the sun. A transparent body is one that allows practically all the light to pass through and thus may be seen through, as a windowpane. A translucent body is one that allows part of the light to pass through and cannot be seen through, as the frosted glass of an incandescent lamp. An opaque body is one that allows no light to pass through, as a stone or a brick. A ray of light is a line that represents the direction along which light travels. A beam of light is a number of parallel rays. A pencil of light is a number of rays passing through a point called a focus.

The moon is passing over part of the face of the sun. In the region where this eclipse is visible the shadow on the earth is a penumbra.

Buing Galloway

ANSWER THESE QUESTIONS

1. What are some of the principal theories of light? What problems arise in accepting the theories?
2. What experiment indicates that light travels in waves? What experiment indicates that light waves are transverse?
3. What is polarized light? How is polarized light used?
4. How are shadows produced? What is an umbra? a penumbra?



EXPLORING THE UNIVERSE OF LIGHT ENERGY

5. What causes an eclipse of the moon? of the sun?
6. What do we mean by a luminous object? an illuminated object? a transparent object? a translucent object? an opaque object?
7. What is a ray of light? a beam of light? a pencil of light?

SOLVE THESE PROBLEMS

1. A pole 6 ft. long casts a shadow 7.5 ft. long. How high is a flagstaff that casts a shadow 80 ft. long?
2. How high is a tree whose shadow is 20 ft. long, if the shadow of a yardstick held vertically is one foot long?

AREA TWO

How Are Speed and Intensity of Light Measured?

"Quick as a flash," we sometimes say when we wish to describe an instantaneous action or movement. The expression really means "quick as a flash of light" and refers to the speed with which light travels. Ordinary experiences fail to reveal that light requires time to travel, and many people think that it travels instantaneously. The scientist, however, never takes anything for granted; he believes that "whatever exists, exists in some measurable quantity," and consequently he has found a method for measuring the speed of light. The following topic explains how he has accomplished this remarkable feat.

Experiments with the speed of light. One of the first persons to try to determine the speed of light was Galileo, who applied a method similar to that used to measure the speed of sound. His attempt was unsuccessful, of course, because of the extremely great speed of light. Not until man began to make an accurate study of the stars through the use of the telescope was any real progress made in measuring the speed of light. The first person to study the speed of light through the movement of heavenly bodies was a Danish astronomer named Römer. In 1676 this

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pioneer scientist, choosing a time when the earth was between the sun and the planet Jupiter, noted the exact time when one of Jupiter's moons passed into the planet's shadow. Six months later, when the sun was between the earth and Jupiter, he found that the eclipse of the particular moon he was observing occurred approximately 1000 seconds later than it had six months before. From this observation he concluded that the delay was caused by the fact that the rays of light in this instance had to travel farther than they did six months before; that is, the distance of 186,000,000 miles across the earth's orbit. Dividing 186,000,000 miles by 1000, he found that the speed of light is approximately 186,000 miles per second.

In 1926 Albert A. Michelson, an American scientist, made a far more accurate study of the speed of light. In performing the experiment, at Mount Wilson Observatory in California, Michelson used eight mirrors joined to form an octagon, that in rotating sent flashes of light to a concave mirror 22 miles away. By adjusting the speed of the rotating octagonal mirror to the speed of the reflection of these flashes of light, he determined the time that it took light to cover the 44-mile distance. On the basis of this experiment he found that light travels 186,292 miles per second. In 1931 he started another experiment, which death prevented him from completing, but which his assistants completed in his stead. In this experiment he removed the air from a pipe one mile long and reflected light back and forth in the pipe by means of mirrors. When the results were tabulated, the speed of light was found to be 186,284 miles per second. Thus for all practical purposes we may consider the speed of light as 186,000 miles, or 300,000 kilometers, per second.

The intensity of light. One of the chief factors that we need to consider in a study of light is the intensity of light. By the intensity of light we mean the brightness of light at its source. Years ago man was little concerned with the intensity of light except the intensity of light from the sun. His chief source of artificial light for many centuries was the candle, which he carried about

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with him from one place to another. When scientists began to study light, the candle was still in use and was therefore accepted as a standard basis for measuring the intensity of light. Candles vary, however, in the intensity of light that they give. Scientists had need for a constant unit of measurement. Therefore they defined a candle power as the light produced by a sperm candle seven-eighths of an inch in diameter and burning 120 grains, or 7.776 grams of wax per hour. Within recent times, since electricity has come into extensive use, the incandescent lamp has replaced the candle as the unit of measurement of luminous intensity. The standard candle power is defined as

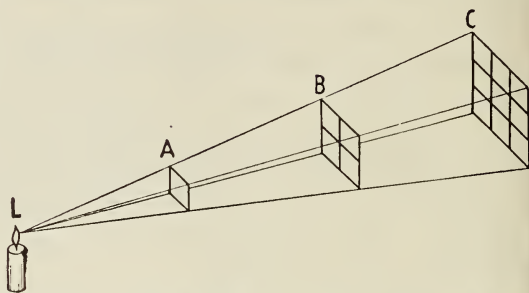
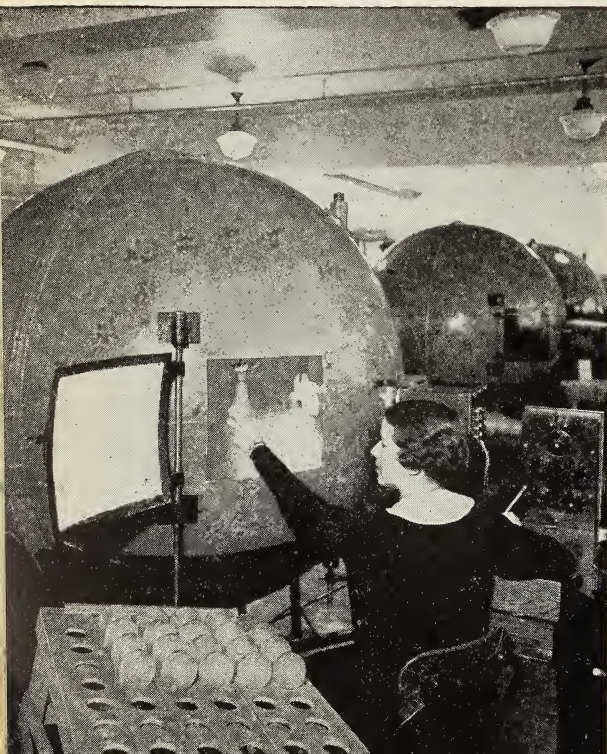


Fig. 309. A surface farther away from a source receives proportionately less light from the source, as illustrated here.

Testing the candle power of light bulbs. The light reflected through the window is the average candle power in all directions.

Courtesy General Electric Company



a specified fraction of the average horizontal candle power of a group of forty-five carbon-filament lamps, a standard preserved in the National Bureau of Standards, Washington, D.C.

The relation of distance to intensity of illumination. Illumination refers to the light that falls upon a surface from natural or artificial sources. One of the chief factors affecting the intensity of illumination is the distance from the source. To understand how distance affects intensity, let us consider the situation presented in Figure 309. In this drawing *L*

Albert A. Michelson
(1852-1931)

Albert Michelson was born in Germany, but came to the United States when a young boy. He graduated from the U. S. Naval Academy, but resigned from the navy to become a professor of physics. His contributions to science include the measurement of the velocity of light in a vacuum, experiments in the behavior of ether, and the interferometer, for measuring the diameters of stars.

Century Photos, Inc.



represents a point of light, *A* a piece of cardboard one inch square placed one foot from the point, *B* a piece of cardboard two inches square placed two feet from the point, and *C* a piece of cardboard three inches square placed three feet from the point. With the cardboards in these positions, cardboard *A* cuts off all the light from cardboards *B* and *C*. If we remove cardboard *A*, we allow the light that fell upon the one square inch of *A* to spread over the four square inches of cardboard *B*. Thus, each square inch of cardboard *B* receives only one-fourth as much illumination as the one square inch of cardboard *A*. If we remove cardboard *B*, we cause the light that fell upon the four inches of cardboard *B* to spread over the nine square inches of cardboard *C*. As a result, each square inch of cardboard *C* receives one-ninth of the illumination that fell on the one square inch of cardboard *A*.

The intensity of illumination is measured in foot-candles. A foot-candle is the intensity of illumination from a source of one candle power at a distance of one foot. The law of illumination is: *The intensity of illumination is inversely proportional to the square of the distance from the source and directly proportional to the candle power of the source.* The law may be expressed in this equation:

$$\text{Intensity in foot-candles} = \frac{\text{candle power}}{(\text{distance in feet})^2}.$$

Example. What is the intensity of illumination from a 32-candle-power lamp at a distance of 4 feet?

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Solution. To solve this problem, we substitute 32 for candle power and 4 for distance in feet in the above equation, as follows:

$$\text{Foot-candles} = \frac{32}{4^2} = \frac{32}{16} = 2.$$

Measuring the intensity of a source of light. The intensity of a source of a light is usually measured by means of an instrument known as a photometer. This instrument in its simplest form is merely a sheet of paper containing a grease spot. If we hold the paper between the eye and a source of light, we find that the spot appears to be brighter than the rest of the paper because it transmits more light. If we look at the paper on the side nearest the source of light, the spot seems darker than the rest of the paper because it reflects less light.

Suppose we continue our experiment by using a device known as the Bunsen photometer, shown in Figure 310, or any other type of photometer found in the laboratory. In the drawing shown here *A* represents a candle, *B* an incandescent lamp, and

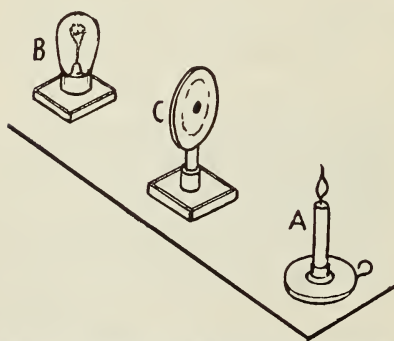


Fig. 310. Diagram of a Bunsen photometer, used to measure the intensity of light.

C a movable cardboard screen containing a grease spot. When we set the screen equally distant between the two lights, the grease spot appears darker than the rest of the cardboard on the side facing the strong electric light and lighter on the side facing the candle. If we move the screen farther from the electric light and closer to the candle, we find a location between the two where the intensity of illumination is

the same for both sides and the spot almost disappears. If we apply the law of foot-candles governing intensity in relation to distance and let $(C.P.)_1$ and d_1 represent the intensity of light and the distance from the source of light respectively on one side of the photometer, and $(C.P.)_2$ and d_2 the intensity of light and

distance on the other side of the photometer, we may derive the following equation, known as the photometer equation:

$$\frac{(C.P.)_1}{(d_1)^2} = \frac{(C.P.)_2}{(d_2)^2}, \text{ or } \frac{(C.P.)_1}{(C.P.)_2} = \frac{d_1^2}{d_2^2}.$$

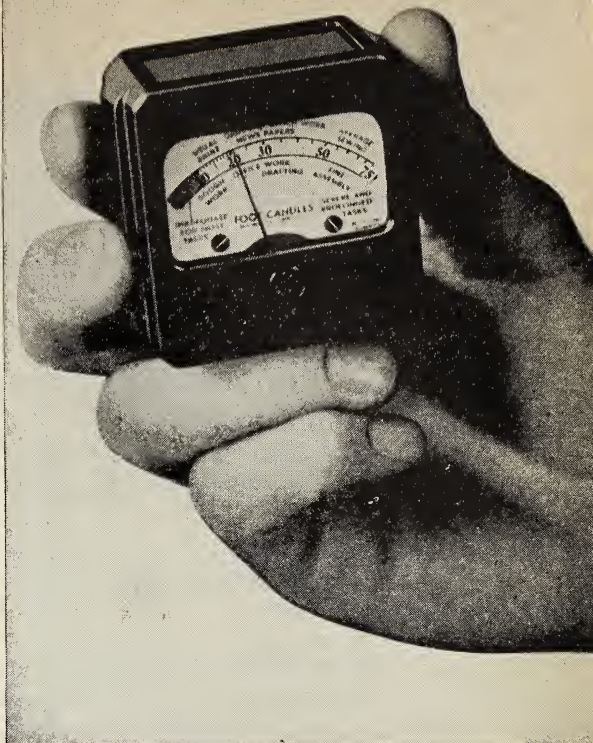
Example. What is the candle power of a lamp 40 centimeters from a screen that gives the same light as a standard candle 10 centimeters from the screen?

Solution. To solve this problem, we substitute 1 for $(C.P.)_1$, the candle power of the standard candle, 10^2 for d_1^2 and 40^2 for d_2^2 , and arrive at the equation:

$$\frac{1}{(C.P.)_2} = \frac{10^2}{40^2}, \text{ or } 100 (C.P.)_2 = 1600, \text{ or } (C.P.)_2 = 16.$$

Another instrument that is used in measuring the intensity of illumination is the photoelectric foot-candle meter. This device consists of a light-sensitive disk that generates a photoelectric current when illuminated. Connected in the circuit is a microammeter with a dial calibrated in foot-candles. The current that is generated by the light-sensitive disk of the foot-candle meter is proportional to the intensity of illumination. The reading on the dial of the instrument indicates the number of foot-candles of illumination.

The efficiency of a lamp. A lamp, if nothing obstructs its radiation, radiates light in all directions. Because of this fact we must think of the receiving surface as the inside surface of a sphere. At a distance of one foot the receiving surface is the inside surface of a sphere with a radius of one foot, the area of which surface is 4π square feet. The efficiency of a lamp is measured in lumens per watt. A lumen is the amount of light transmitted by a lamp



Courtesy General Electric Company

A photoelectric foot-candle meter. It will measure intensities up to 75 foot-candles.

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of one candle power to one square foot of surface at a distance of one foot. To find the efficiency of a lamp on the basis of the foregoing information, we apply the following equation:

$$\text{Efficiency} = \frac{\text{candle power} \times 4\pi}{\text{watts}} = \frac{\text{lumens}}{\text{watts}}$$

Example. What is the efficiency in lumens per watt of a 25-watt lamp that shows an intensity of 20 candle power in a test with a foot-candle meter?

Solution. To solve this problem, we substitute in the above equation, 20 for candle power, 3.1416 for π , and 25 for watts as follows:

$$\text{Efficiency} = \frac{20 \times 4 \times 3.1416}{25} = 10.053 \text{ lumens per watt.}$$

The intensity of illumination needed in modern life. The intensity of illumination needed in any situation depends upon the use to be made of the light. In general, on a clear day, we receive 10,000 foot-candles of illumination from natural sources, 8000 foot-candles from the sun and the other 2000 foot-candles from the

Lighting equipment provides well above the light requirements in foot-candles over every part of this great field, where 80,000 people have gathered to see a game of football at night. Thus men make use of lighting to "turn night into day."

Acme



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sky. On cloudy days there is less natural light, and artificial light must be provided in such places as offices, factories, and schools. Artificial light must also be provided to satisfy all the requirements for illumination at night. The following table indicates the illumination requirements in foot-candles for various situations in which people use their eyes. These standards are based upon the common practice followed in the installation of lighting equipment adequate for each situation.

FOOT-CANDLE STANDARDS

Indoor lighting:

Warehouses.....	5-10
Manufacturing plants (rough products).....	10-15
School classrooms.....	12-20
Offices.....	15-25
Drafting rooms.....	25-40
Manufacturing plants (fine products).....	25-50

Outdoor lighting:

Baseball diamonds (infield).....	50
Baseball diamonds (outfield).....	30
Football fields.....	20
Basketball courts.....	20

The quality of light. Whenever we consider the quality of light, we think of daylight as a standard, because it is the kind of light to which people are most universally accustomed. It is in daylight that we most generally judge the appearance of objects. Under the heading of quality we include such characteristics as glare, shadows, and color. By glare we mean any brightness of light that causes discomfort to the eyes or interferes with the vision. To overcome glare, light experts commonly use such protective devices as reflectors and shades. By shadow, as we have already learned, we mean a region of partial darkness caused by an object that obstructs the passage of light. Light experts strive to secure soft, well-illuminated shadows, such as may be obtained by arranging lamps so that two or more contribute to the lighting of all sections of a room. Only in this way can each part of the room be adequately illuminated.

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Artificial light should give the same color quality as daylight; that is, blue should appear blue, red should appear red, and every other color should be easily identified. Experts have worked to get an artificial light that will give the color quality of daylight. The modern fluorescent lamp, which they have developed, provides such light, and the later types of tungsten lamps approximate the light.

Lighting systems. There are three general systems of illumination, classified according to the manner in which the light is distributed: (1) direct lighting, (2) indirect lighting, and (3) semi-indirect lighting. The direct-lighting system is so named because the light passes directly from the source to the object to be illuminated. Inclosing glassware is preferable to open glassware for direct-lighting fixtures because it helps to eliminate glare and sharp shadows. The indirect-lighting system is so named because the light is sent to the ceiling from which it is reflected downward. This system requires brighter sources than the direct system in order to secure the same intensity of illumination, but it is more restful to the eyes because glare is reduced and shadows are softened. The semi-indirect system is a combination of the other two systems, light being diffused directly downward by special inclosing glassware and also reflected from the ceiling. This system requires less intensity of source than the indirect system but provides approximately the same benefit.

ANSWER THESE QUESTIONS

1. How did Galileo attempt to measure the speed of light? How did Römer proceed to determine the speed?
2. What experiments did Michelson perform to determine the speed of light? What speed may we use for general calculations?
3. What is meant by the intensity of light? What unit is used in measuring the intensity of light?
4. What relation exists between the intensity of illumination and distance from the source? What equation may be used in calculating footcandles?
5. What is a photometer? How is a photometer used?

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6. What equation is used in finding the efficiency of an electric lamp? Why is the number of lumens divided by the number of watts?

7. What is meant by direct lighting? indirect lighting? semi-indirect lighting? What are the relative merits of the systems?

SOLVE THESE PROBLEMS

A

1. If the light from Arcturus that was used to open the Century of Progress Exposition had traveled for forty years to reach the earth, how far away is the star?

2. In winter the sun is about 92,500,000 mi. from the earth. How long does it take light energy from the sun to reach the earth?

3. Light requires about four years to reach us from the nearest fixed star. How many miles away is this star?

4. Compare the intensity of the illumination from the same source on a book held 4 ft. away with the intensity when the book is held only 3 ft. away.

5. How far from a lamp must a book be held to receive three times as great an intensity of illumination as the wall 8 ft. from the lamp?

6. If a standard candle is 9 cm. from a screen, where must a 20-C.P. lamp be placed to produce the same intensity of illumination?

7. A Bunsen photometer is equally illuminated by two lamps. One of the lamps has 32 C.P. and it is 60 cm. from the photometer. If the other lamp is 40 cm. from the photometer, what is its candle power?

8. What is the intensity of illumination in foot-candles of a book held 2 ft. from a 20-C.P. lamp?

9. How many foot-candles of illumination does a draftsman receive on his desk from a 100-watt lamp (which is rated at 0.8 watt per C.P.) placed 2 ft. above his desk? What is the efficiency in lumens per watt?

B

10. Two sources of light, one a 25-C.P. lamp, the other a 100-C.P. lamp, are placed 96 cm. apart. Where must a screen be placed to receive the same intensity of illumination on each side?

11. If it takes 10 sec. to make a photographic print held 2 ft. from a 50-C.P. lamp, how many seconds should be required when it is held 3 ft. from a 100-C.P. lamp?

12. What is the lumen efficiency of a 100-watt lamp of 125 C.P.?

What Are the Principles of Reflection of Light Waves?

The reflection of light waves is an important topic in physics because it explains the use of mirrors. Mirrors are extremely useful devices, especially for personal use. You can scarcely imagine, for instance, a man shaving or a woman combing her hair without looking into a mirror. Most mirrors are made flat, because the images from such mirrors reveal true size and shape. Concave and convex mirrors, on the other hand, present optical illusions and are frequently used in fun houses to make people look disproportionately tall or fat. The following pages will explain the principles of reflection and also how reflection takes place from flat, concave, and convex mirrors.

How light is reflected. Light waves are affected by every medium through which they pass and by every surface that they strike. Most objects absorb or reflect light waves. Dark objects absorb a high percentage of light waves, whereas light objects and particularly smooth, shiny objects reflect a high percentage of light waves. When the waves of light strike their surfaces, water, glass, and other transparent substances transmit light, but they also reflect light.

The amount of light reflected by an object depends upon the nature of the material, the character of the surface, and the angle at which the light strikes the object. Glass is a better reflector than wood. A polished stone is a better reflector than a rough stone. The sun causes more glare from the surface of a body of water in the forenoon or afternoon than at noonday because the rays strike the water obliquely.

The law of reflection. The reflection of light is somewhat like the rebounding of a ball when it strikes a wall. If the ball strikes the wall perpendicularly to the surface, it rebounds straight

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toward the thrower. If the ball strikes the wall at an angle, on the other hand, it will rebound from the wall at an angle and move away from the thrower. To see what happens in reflection, let us examine the drawing in Figure 311, in which AD represents a ray of light, commonly known as the incident ray, striking a mirror at D , and BD represents the reflected ray of light. The perpendicular line CD in the drawing is known as the normal, the angle ADC is called the angle of incidence, and the angle BDC the angle of reflection. According to the law of reflection, *the angle of incidence always equals the angle of reflection, and the incident ray, the normal, and the reflected ray lie in the same plane.* A single ray of light always

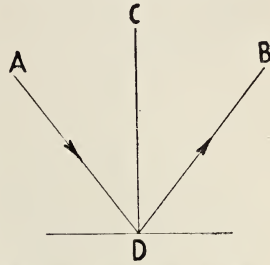


Fig. 311. Diagram of a ray of light reflected at an angle.

obeys this law and is said to be regularly reflected. Parallel incident rays such as those from the sun, which are approximately parallel, also obey the law if they strike a regular surface. The greater the quantity of reflection from any surface, the less of the surface we see. A perfect reflecting surface is invisible, and many people have stumbled into plate-glass doors because this is true. Large mirrors about a room make the room seem larger because we see reflected objects rather than the mirrors.

Most rays of light are scattered or diffused when they strike a reflecting surface, because the surface is more or less irregular. Therefore, when a beam of light falls upon a wall, the rays strike a multitude of tiny surfaces that turn the rays back in many directions. Each ray is reflected regularly according to the law of reflection; but if we consider all the rays together, we may say that they are reflected irregularly, or diffused. Diffusion is especially important because it scatters light over places to be lighted that would otherwise be dark, such as the corners of rooms and the areas under shade trees. Much of the light that comes to us from the sun is diffused from dust particles. The diffusion of the sun's rays by atmospheric particles is responsible for the color of the sky, whether it be blue or gray.

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To compare regular and diffused reflection, let us examine the three drawings shown in Figure 312. The left-hand drawing illustrates the incident ray AD and the reflected ray BD forming

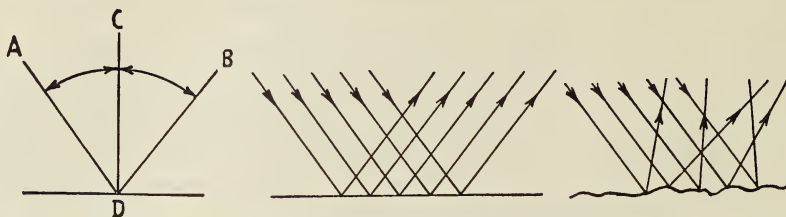


Fig. 312. Regular and diffused reflections caused by surfaces struck by light rays. The law of reflection illustrated above results in the diffusion of light in many areas.

equal angles at D with the normal line CD . The center drawing illustrates parallel incident rays striking a plane surface, the reflected rays being parallel because the angles of reflection are the same. The right-hand drawing illustrates parallel incident rays striking an irregular surface, the reflected rays being diffused irregularly because the angles of reflection differ. Thus, whether reflection is regular or diffused depends entirely upon the character of the reflecting surface.

How the reflection of light produces images. Whenever we look into a plane mirror, or a mirror with a flat surface, we see an image of our face, because a ray of light is reflected from every point of the image back to our eyes. The image is exactly the same size as our face, and seems to be as far behind the mirror as we are in front of it. To understand why the image seems to be back of the mirror, let us examine the drawing in Figure 313. XY in this drawing represents a mirror, A represents a point on our face from which a ray of light strikes the mirror at N , (1) is the angle of incidence, (2) is the angle of reflection, and

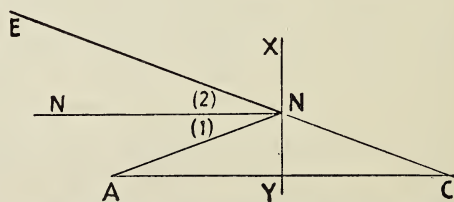


Fig. 313. Diagram showing how an image results from the reflection of light from a flat surface.

E represents our eye receiving the reflected ray. The reflected ray in this instance seems to follow a straight line from point C as far behind the mirror as point A is in front. By means of geometry we can readily prove that A and C lie on a straight line perpendicular to the mirror and that they are equidistant from the surface of the mirror.

If we think of light as traveling in waves, we may assume that it travels in expanding wave fronts as shown in Figure 314. In this drawing P represents a point source of light and AB and A_1B_1 represent wave fronts traveling from the source. The farther each front travels from the

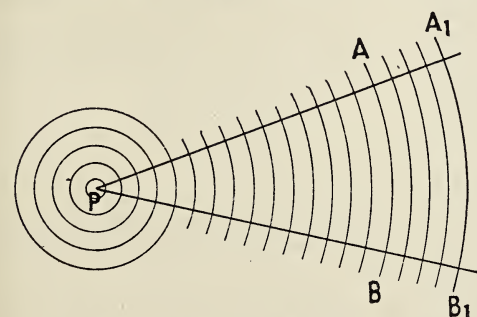


Fig. 314. From the source P light is transmitted in waves which travel outward in all directions.



Paul Photos

The virtual image seen in the mirror is as far behind the mirror as the object is in front.

source, the more nearly it approaches a straight-line, or plane wave front. The lines PA and PB , which represent the radii of the waves, are known as rays. For practical purposes, in locating images formed by the reflection of light from a mirror, we may think of light as traveling along the rays. When such a method of locating images is used, it is known as the ray method.

As indicated in the adjacent drawing, when light waves travel outward from a point, they form a series of concentric circles or arcs about the point. The relative size of the circle or arc at any particular distance

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from the point is known as the curvature of the wave. This curvature depends upon the distance from the point; the greater the

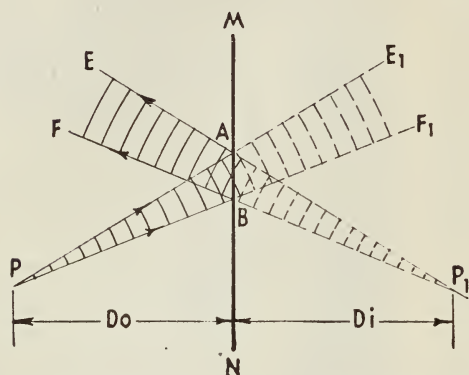


Fig. 315. Light from the point P is reflected between the lines AE and BF when it strikes the surface MN .

such as MN , they turn back between the lines AE and BF as if they had originated at P_1 . In other words, while P is the real origin of the waves reflected in the mirror, the image P_1 seems to be the origin. The image P_1 , in such a case, is known as the virtual image of P . The image distance Di is equal to the object distance Do , and the image is the same size as the object.

How waves are affected by curved mirrors.

When waves with plane fronts, such as those from the sun, strike a convex spherical mirror, represented by the heavy line in Figure 316, the center of the waves reaches the mirror before the ends reach the mirror. As a result of this occurrence the waves are reflected in curves

as if they came from the point F . This point from which the reflected waves seem to come is known as the principal focus

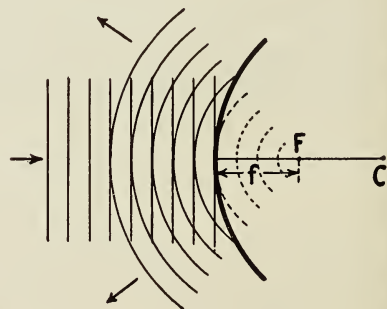


Fig. 316. Effects of a convex spherical mirror as it reflects light waves with plane fronts.

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of the mirror, and the distance from F to the mirror, indicated by f , is known as the focal length. The point F is also called the virtual focus, since the waves do not really come from this point. When light waves diverge in this manner, they are said to be positive. Since f , the focal length, represents the radius of curvature, we may express the curvature of the waves at the mirror as $1 \div f$. Since the curvature of the incident waves is 0, it is evident that the convex mirror adds a curvature of $1 \div f$. A convex mirror always adds $1 \div f$ to any incident wave.

When curved light waves strike a convex spherical mirror, they are reflected in much the same manner as plane waves. If we let D_o represent the distance from an object to the mirror, and D_i represent the apparent distance from the image to the mirror, then $1 \div D_o$ represents the curvature at the mirror of the waves from the object, and $1 \div D_i$ the curvature at the mirror of the waves forming the image. On the basis of these quantities we derive an equation for reflection of curved waves as follows:

$\frac{1}{D_o} + \frac{1}{f} = \frac{1}{D_i}$. Since the latter expression is positive, the reflected waves from the surface of a convex mirror always diverge. As a result, the image is always behind the mirror and consequently is a virtual image.

When waves with plane fronts strike a concave mirror, represented by the heavy line in Figure 317, the ends of the waves reach the mirror before the center reaches the mirror. As a result, the waves are reflected in curves that converge at point F . Since these waves converge and do not diverge as in the case of the convex mirror, they are said to be negative. In view of this fact, we see that a concave mirror subtracts a curvature equal to $1 \div f$. If we let D_o represent the distance from the object to the mirror as before, and D_i represent the apparent distance from the image to the mirror, we derive the following equation for reflection from a concave

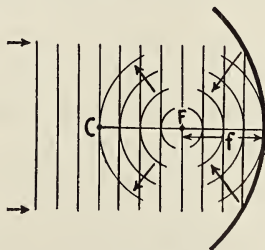


Fig. 317. Plane waves reflected from concave mirror with converging curvature.

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mirror: $\frac{1}{D_o} - \frac{1}{f} = \pm \frac{1}{D_i}$. For real images we may write the equation

for reflection from a concave mirror as follows: $\frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{f}$.

The image by reflection of rays. Now let us consider a method of locating the image of a point, such as P in Figure 318, by means of the law of reflection; namely, that the angle of incidence equals the angle of reflection. To locate point P_1 we draw rays from the

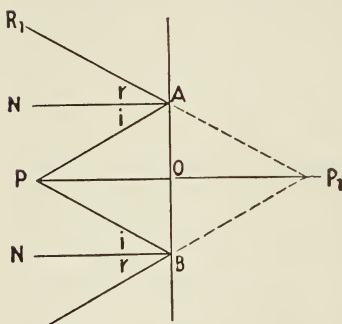


Fig. 318. Diagram showing how angles of incidence and reflection are drawn in order to locate a point.

point to the mirror, as the ray PA , and construct the angle of incidence PAN and the angle of reflection R_1AN . In the same way we locate other reflected rays. If we continue the rays back of the mirror, we find that they intersect at point P_1 , the image of P .

A line drawn from the object perpendicular to the mirror passes through the image. Stated in other words, a line drawn from a point in the object to the image of that point is always perpendicular to the mirror.

This is true for all mirrors, plane and curved.

To find a method for locating images in convex mirrors, let us consider the drawing in Figure 319. In this drawing C is the center of curvature of the mirror and F is the principal focus or the virtual focus. Point O is called the optical center of the mirror and line OC the principal axis of the mirror. When parallel rays strike the mirror, they are reflected as if they came from point F , or the principal focus, which is virtual. Ray AX , for example, is reflected along path XR as if it came from F . When rays strike the mirror perpendicularly to its surface, they are reflected back

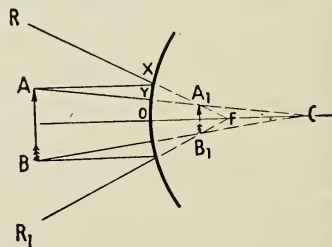


Fig. 319. Diagram of method used to locate an image in a convex mirror.

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over the same paths as if they came from point C . Thus ray AY turns back over the path YA as if it came from C . By examining the drawing, we find that the image of A is on both lines AC and FX , and therefore is at their intersection, A_1 . Also, if the image of B is located at B_1 , the line A_1B_1 is the image of AB . The image is smaller than the object and is a virtual image.

The method of locating images in concave mirrors is the same as that used in the location of images in convex mirrors. To understand what this method is, let us examine the drawings in Figure 320. In the upper drawing the object is between the principal focus and the mirror, and the resulting image is virtual, erect, and enlarged. In the lower drawing the object is at a greater distance from the mirror than its focal length, and the resulting image is real, inverted, and enlarged.

If conditions are reversed and the object is placed at A_1B_1 , the image will be located at AB . That is, any two points so located that light diverging from one converges at the other are conjugate foci.

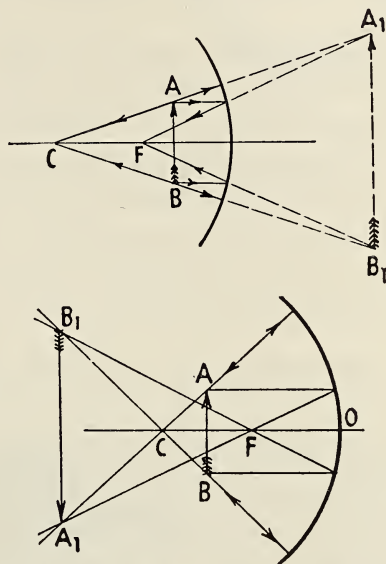


Fig. 320. Diagrams showing how images may be accurately located in concave mirrors.

Summary of images found in curved mirrors. From the foregoing descriptions and drawings, we may summarize the following facts about images in curved mirrors:

1. That all images formed in convex mirrors are virtual and smaller than the object.
2. That the image formed in a concave mirror is a virtual image when the object is closer to the mirror than F ; that is, when $D_o < f$. The image in this instance is larger than the object.

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3. That the image in a concave mirror is a real image when the object is farther from the mirror than F or when $D_o > f$.
4. That the real image is larger than the object when the object is between F and C , or $D_o < 2f$ or r , where r is the radius of curvature of the mirror.
5. That the real image is the same size as the object when the object is at the center of curvature, or $D_o = r$ or $2f$.
6. That the real image is smaller than the object when the object is farther from the mirror than C , or when $D_o > 2f$.

Relation of the size of an object and its image formed by curved mirrors. The relative sizes of the image and the object are directly proportional to their distances from the mirror. If L_i represents the length of the image, L_o the length of the object, D_i the distance from the image to the mirror, and D_o the distance from the object to the mirror, we may express the relationship as follows:

$\frac{L_i}{L_o} = \frac{D_i}{D_o}$. The ratio $\frac{L_i}{L_o}$ is called the linear magnification.

Giant searchlights such as the searchlight shown here are used in warfare to scan the skies for enemy aircraft. The reflector is a giant parabolic mirror.

Ferdinand Hirsh



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Spherical aberration. Not all the parallel rays that strike a concave spherical mirror are brought to a focus at a point. This fact can be demonstrated in the laboratory by means of an instrument called an optical disk. Figure 321 shows the working parts of this instrument. Rays of light from the electric lamp at the left of the drawing enter through narrow openings in the border of the disk. These rays strike a mirror in the center of the disk, and their reflection is readily observed against the background of the disk. As shown in the figure, the parallel rays that strike the mirror near the edges are reflected at such an angle that they cross nearer the mirror than the rays that strike the mirror near the optical center. The deviation from a single-point focus on the part of the reflected parallel rays is known as spherical aberration. Such deviation results in indistinct images, and hence steps must be taken to correct the condition. One method is to cut off the outside rays, and another method is to use a parabolic mirror, or one especially curved to bring the parallel lines to a single focus, as shown in Figure 322. Searchlights and automobile headlights are equipped with parabolic mirrors to bring reflected parallel rays to a focus.

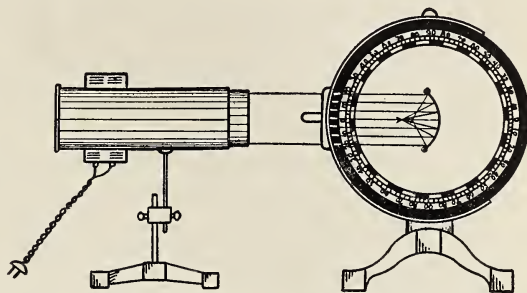


Fig. 321. The optical disk shows the effect of rays striking a concave spherical mirror, resulting in spherical aberration.

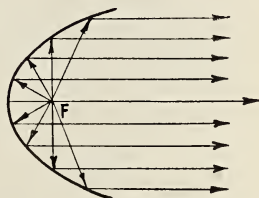


Fig. 322. A parabolic mirror used to correct aberration.

ANSWER THESE QUESTIONS

1. What factors determine the amount of light reflected from the surface of an object?
2. What is the law of reflection? What is the angle of incidence? the angle of reflection?

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3. Why is much of the light diffused that comes from the sun? What do you understand by diffused light?

4. How is light reflected from a plane mirror? How does the image compare with the real object in size and in distance from the mirror?

5. Why is the image from a convex mirror always a virtual image? Why is it smaller than the real object?

6. Why may the image from a concave mirror be either virtual or real? Why may it be either larger or smaller than the object that produces the image?

7. What method may you employ to locate the image of an object reflected from a plane mirror? the image of an object reflected from a convex mirror? from a concave mirror?

8. What is meant by spherical aberration? How is spherical aberration corrected?

SOLVE THESE PROBLEMS

1. A man approaches a plane mirror at the rate of 9 feet per second. At what rate does he approach his image?

2. Show by means of a drawing that a man 6 feet in height can see a full-length image of himself in a plane mirror 3 feet in height.

3. Find the focal length of a concave mirror if an object 20 centimeters in front of the mirror produces a real image 60 centimeters from the mirror.

4. If the focal length of a concave mirror is 10 centimeters, and an object is situated 8 centimeters from the mirror, how great will be the apparent distance from the mirror to the image? What kind of image will be formed? If the object is 4 centimeters long, what will be apparent length of the image?

5. A convex mirror has virtual focus 8 centimeters behind the mirror. If an object is placed 20 centimeters in front of the mirror, where will the image be? If the object is 5 centimeters long, what is the length of the image?

6. If the driver of an automobile uses a small convex mirror with a radius of curvature of 6 inches, and he observes in the mirror an image $\frac{1}{4}$ inch high of an object 100 feet away, how tall is the object that produces the image?

7. How far in front of a concave mirror whose focal length is 12 inches must an object be placed to throw an image on a screen 5 feet from the mirror? If the object is one inch in length, how long is the image?

AREA FOUR

What Are the Principles of Refraction of Light Waves?

At one time or another when walking along the shore of a lake or the bank of a stream we may have noticed that a stick appeared to be bent where it projected from the water. We may even have pulled the stick from the water to see whether it was crooked or straight. The optical illusion in this instance was caused by the refraction or bending of light waves that occurs when light passes from a medium of one density to a medium of another density. In this area we shall consider first the principles of refraction and then observe how the principles are applied in the construction and use of lenses, such as those contained in spectacles, cameras, microscopes, telescopes, and other similar devices. Refraction differs from reflection in that refracted waves pass through a medium, whereas reflected waves are always turned back.

How light waves bend. To learn how light waves bend when passing obliquely from one medium to another of different density, let us place a dime on the bottom of an opaque vessel. We look straight down at the coin from position E , as in Figure 323, and then move to one side until the side of the vessel causes the coin barely to pass out of our range of vision. Looking in the direction of the coin we now pour water into the vessel. When the water has reached a certain height, the coin will come into view and present the appearance of having risen from point P to point P_1 .

Now let us consider why the coin has again come into sight. The arc AOB represents the wave front of a wave from P with the point O just

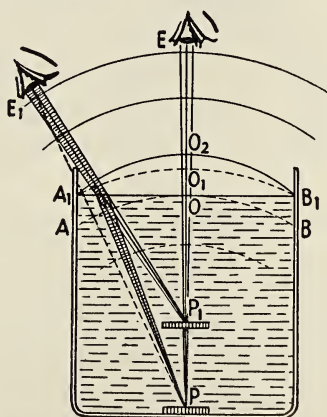


Fig. 323. Bending of light rays in an opaque container of water.

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leaving the water. In going into air, this part of the wave travels with greater velocity. The point O travels to O_2 instead of to O_1 while the points A and B are traveling to A_1 and B_1 . If the velocity of light were the same in air as in water, the wave front at the instant the points A and B reach the air would be the dotted line, $A_1O_1B_1$. Since the velocity is not the same, the wave front now is the arc $A_1O_2B_1$. This arc has a greater curvature than $A_1O_1B_1$, and the center of the curvature of the waves

is at P_1 . Thus the object P appears to the observer to be at P_1 . This change in the direction of waves of light is called refraction. The refraction of light waves passing from water to air explains also why it is difficult to judge the depth of the coin in the water.

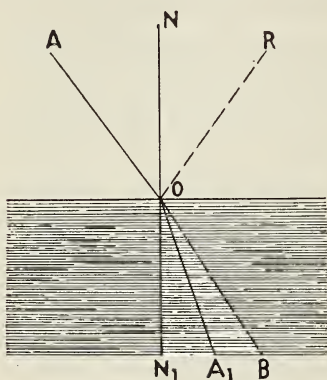


Fig. 324. Drawing showing what happens when light falls on water

When a beam of light falls on water, as shown in Figure 324, a part is reflected in accordance with the laws of reflection, and a part passes into the water and is refracted along the line OA_1 . OA is the incident ray, and OA_1 the refracted ray. The $\angle AON$

is the angle of incidence, the $\angle A_1ON_1$ the angle of refraction, and the $\angle A_1OB$ the angle of deviation. When light passes obliquely from a rarer to a denser medium, it is bent toward the perpendicular or normal. When light passes obliquely from a denser to a rarer medium, it is bent away from the normal.

Path of light from air to glass. With the optical disk it can be shown that the angle of refraction increases with an increase of the angle of incidence. In the first drawing in Figure 325 the ray of light does not bend when it enters the glass, because it strikes the glass on a normal to the surface of the glass. It does not bend when it leaves the glass, because it passes through the glass along a radius that is a normal to the curved surface. In the second drawing the disk is turned so that the ray of light

REFRACTION OF LIGHT WAVES

strikes the surface of the glass obliquely, and the ray is bent toward the normal as it enters the glass. Again it does not bend at the curved surface of the glass, because it still falls along a normal. The third drawing illustrates conditions similar to those

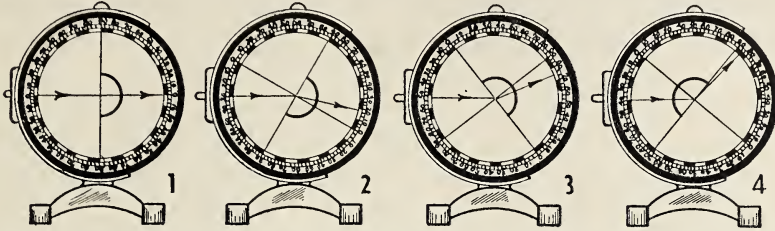


Fig. 325. The four optical disks shown in the drawing indicate the relation of the angle of refraction of a ray of light to the angle of incidence as the ray strikes the glass.

in the second drawing, except that the angle of incidence and the angle of refraction are larger. The last drawing illustrates the light entering the curved surface and passing along a normal to the center. The ray continues straight until it leaves the glass obliquely at the center and enters a medium of lesser density where it is bent away from the normal. The angle of incidence is about 40° , and the refracted ray is bent so as to make the angle of refraction very nearly 90° .

Critical angle and total reflection. As the angle of incidence is made larger, the refracted ray approaches 90° until it becomes coincident with the surface. The angle of incidence at which the refracted ray makes an angle of 90° with the normal is called the critical angle. When the incidence angle is made larger than the critical angle, as shown in Figure 326, no light passes into the rarer medium and total reflection results. Total reflection occurs only when light passes from a denser medium to a rarer medium. A diamond sparkles because its critical angle is small.

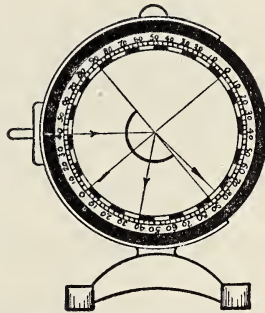


Fig. 326. An optical disk with the incident angle greater than the critical angle.

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Index of refraction. As has been shown, the refraction of light is due to the change of velocity of light as it passes from one medium to another of different density. The amount of bending is determined by the ratio of the two velocities. The index of refraction is the ratio of the velocity of light in air to its velocity in another medium, as follows:

$$\text{Index of refraction} = \frac{\text{velocity in air}}{\text{velocity in another medium}}.$$

This is sometimes called the relative index, for the absolute index is the ratio of the velocity of light in a vacuum to the velocity in a given medium. For practical purposes, however, the relative index is taken.

A study of Figure 327 shows the relation between the change in speed and the change in direction of light. AB represents the wave front of a plane wave in air, and CD the wave front of the wave a little later in the denser medium. The part of the wave at A is slowed by the denser medium

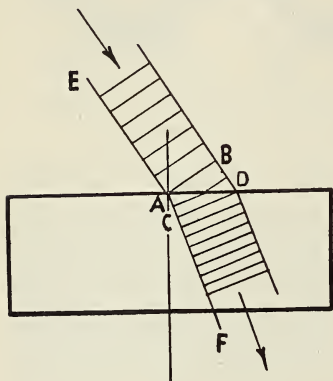


Fig. 327. Speed and direction of light changed by a denser medium.

and travels from A to C , while the other part in air travels from B to D . CD is then the new wave front. Since all waves move in a direction perpendicular to the wave front, the change of direction is from that represented by EA to that represented by AF . BD and AC represent distances traversed in equal periods of time and are directly proportional to the velocities in the two media. Thus the ratio $\frac{BD}{AC}$ is the index of refraction.

Another way of finding the index of refraction. The preceding discussion indicates that we can find the index of refraction of one substance relative to another by dividing the velocity of light in one substance by the velocity in the other. Because it is very difficult to measure the velocity of light directly in any medium,

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a simpler way of finding the relative index of refraction is needed. The simpler method is derived from geometry.

In Figure 328 the wave fronts AB and CD are the same as those shown in Figure 327. EA is equal to FA , and EM and FN are drawn perpendicular to MN . The right triangles ABD and AME are similar, since angle 1 equals angle 2. Therefore, $BD:EM$

$$= AD:EA, \text{ or } \frac{BD}{AD} = \frac{EM}{EA}.$$

Also, right triangles DCA and ANF are similar, since angle 3 equals angle 4.

Thus, $AC:FN = AD:FA$, or $\frac{AC}{AD} = \frac{FN}{FA}$. If the original

equation is divided by the second equation and the equal terms AD and AD on the left side and FA and EA on the right side are cancelled

out, the result is: $\frac{BD}{AC} = \frac{EM}{FN}$.

Since the first ratio $\frac{BD}{AC}$ of the above equation is the index of refraction indicated in Figure 327, the second ratio also indicates the index of refraction. The index can be found by tracing a ray of light, such as EAF in Figure 328, across the boundary separating two substances of different densities and dividing the length of EM by the length of FN .

Refraction applied to lenses. Now that we understand the principles of refraction, we are ready to consider refraction in relation to lenses. Lenses, as we know, are made from glass or other transparent material. They must permit the passage of light because the essential purpose of lenses is to change the direction of light rays. Among the different kinds of lenses are those found in spectacles, cameras, field glasses, microscopes, and telescopes.

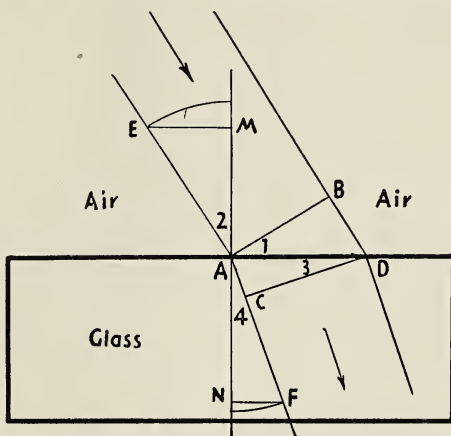


Fig. 328. Diagram showing method for determining the index of refraction of a given substance.

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The lenses in these devices vary greatly in shape and in materials. Both of these factors have much influence on the character of the images formed because of refraction. With reference to shape, lenses are generally either convex or concave:

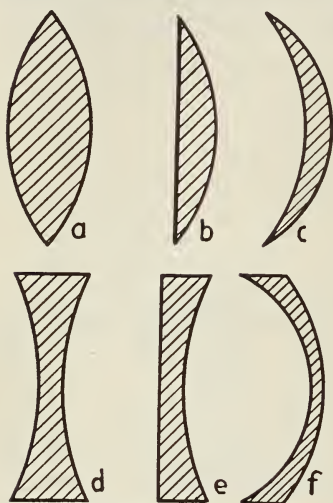


Fig. 329. Concave and convex lenses drawn to show differences in form.

1. Convex lenses are thicker in the middle than at the edges and are made in three shapes as illustrated in Figure 329 *a, b, c*.
2. Concave lenses are thinner in the middle than at the edges and are also made in three shapes, as shown in Figure 329 *d, e, f*.

Lenses are transparent, and hence they permit light rays to pass through them, but they are more dense than air, and for this reason they cause light rays to be refracted. Since they refract the light rays from any object, they form an image that is not identical in size or position with that of the object. In view of the fact that

lenses are widely used, we doubtless are already acquainted with certain principles of refraction. The following topics will explain how convex and concave lenses affect rays of light.

Images produced by

convex lenses. Figure 330 shows parallel rays passing through a convex lens and converging toward the point *F*. The point to which the lens causes the light to converge, or come to a point, is called the focus. The distance from the lens to the principal focus is called the focal length. Lenses form

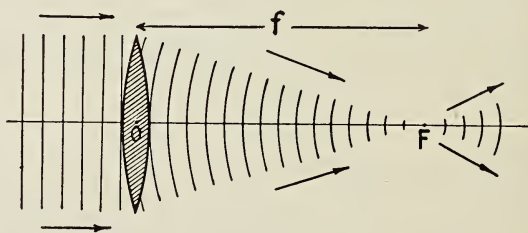


Fig. 330. Parallel rays of light passing through a double convex lens and converging to a point called the focus.



The image of a screen in the end of the box is formed on the cardboard. What kind of image is formed? What is the relationship of the focal length of the lens, the image distance, and the object distance?

images by refracting the light that passes through them. As has been explained, refraction is caused by a change in the wave front of light as it passes from one medium into another in which the velocity is changed.

Figure 330 shows the change in wave front of the light coming from a distant object as it passes through the lens. The part of the wave that passes through the middle of the lens is retarded most, and the part at the thinner edges is retarded least. The wave, as it leaves the lens, has a converging, or concave, wave front and comes to a point at F . If the lens is thin, OF may be taken as the radius of the light wave as it leaves the lens. Then

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$\frac{1}{OF}$ or $\frac{1}{f}$ represents the curvature of the wave as it leaves the lens.

Since this wave is converging, we give it a minus sign (-).

Since a plane wave has zero curvature and the emerging curvature is $-\frac{1}{f}$, the lens has subtracted a curvature equal to $\frac{1}{f}$.

A convex lens always subtracts $\frac{1}{f}$ curvature from any wave that strikes it.

The object is at P , as in Figure 331. OP is the object distance D_o . The image is at P_1 , and the image distance is OP_1 or D_i .

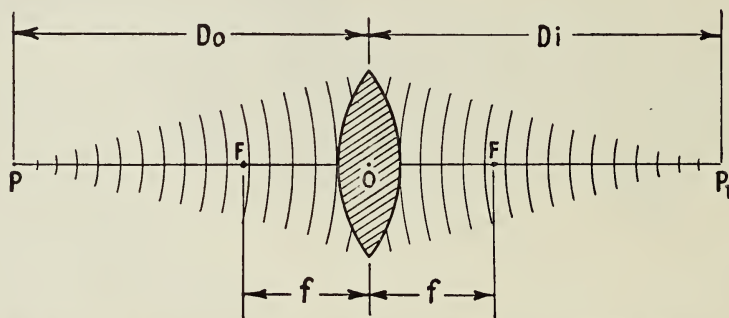


Fig. 331. A real image formed by passing waves from an object through a lens.

The change produced by the lens is represented by the equation:

$\frac{1}{D_o} - \frac{1}{f} = \frac{-1}{D_i}$. $\frac{1}{D_o}$ represents the curvature of the wave coming

from the object as it enters the lens and $\frac{-1}{D_i}$ the concave curvature of the wave as it leaves the lens. This wave converges to the point P_1 , which is the image of P . This is a real image when the emerging wave is concave, or converging. This happens only when D_o is greater than f , or the object is farther from the lens than its focal length. That is, $\frac{-1}{D_i}$ has the minus sign only when $\frac{1}{D_o}$ is less than $\frac{1}{f}$.

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Convex lenses form virtual images when the object is closer than the focal point, as in Figure 332. Here the wave is diverging when it leaves the lens, but its curvature has been diminished. For this reason the light wave seems to come from a point on the same side of the lens as the object, but farther from the lens than the object. The image of A is at A_1 and is a virtual image. This effect is represented by the following equation:

$$\frac{1}{D_o} - \frac{1}{f} = + \frac{1}{D_i}$$

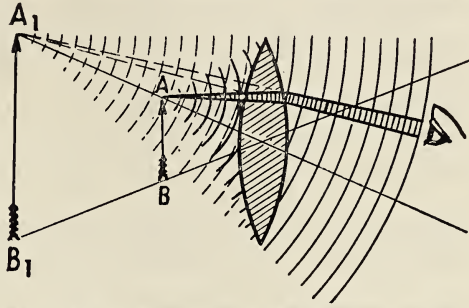


Fig. 332. Diagram showing the behavior of light as a virtual image is formed through a convex lens.

Images produced by concave lenses. The drawing at the left in Figure 333 shows what happens when plane wave fronts reach a concave lens. The plane waves, indicated by the straight lines at the left of the lens, are retarded more at points A and B than at point C , since the waves at these points must pass through

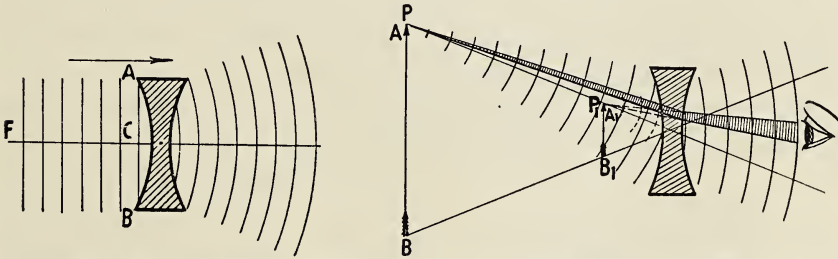


Fig. 333. Diagrams showing divergence, or convection, of light waves resulting from passing through a concave lens. The waves are retarded by the thick part of the lens.

thicker parts of the lens. The light emerges from the lens with a diverging, or convex, wave front indicated by the curved lines at the right of the lens. The center of curvature of this wave is at point F , which is called the principal focus of the lens. Since the light appears to come rather than actually comes from point F , the point is called a virtual focus.

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The curvature of the emerging waves as shown at the right in Figure 333 is expressed by $\frac{1}{f}$. Since the curvature is convex, or diverging, $\frac{1}{f}$ has a plus sign. The change produced by the concave lens on light waves, with plane wave front, is expressed by the following equation: $0 + \frac{1}{f} = +\frac{1}{f}$. For any light waves, the equation is: $\frac{1}{D_o} + \frac{1}{f} = +\frac{1}{D_i}$. In the drawing at the right in Figure 333, P is the point on the object from which the light waves curve. The curvature of waves coming from it, at the instant they strike the lens, is $\frac{1}{OP}$ or $\frac{1}{D_o}$. The curvature of the light waves emerging from the lens, $+\frac{1}{D_i}$, is a diverging curvature. Since the curvature is always an increased convex curvature, the image is always on the same side of the lens as the object, and always between the object and the lens. Concave lenses form only virtual images.

Images of large objects. For the sake of clearness we have considered the waves as coming from a single point on the object. However, it should be understood that an object such as a tree is made up of many points, and each point sends waves to the

lens; the lens acts upon these waves just as we have seen it act on the waves from the single point considered. This is made clearer by Figure 334. AB is a distant tree, and A and B are points at the top

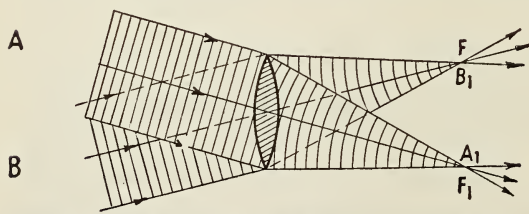


Fig. 334. Wave fronts from several points striking a convex lens are focused and the image is inverted.

and bottom of the tree. These points are sending nearly plane waves which are brought to a focus at points A_1 and B_1 .

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Conjugate foci for lenses. Divergent waves, as in Figure 335, are made convergent by the lens. They are focused at A_1 and B_1 , and form image A_1B_1 of the object AB . Figure 335 shows A and A_1 to be conjugate foci; that is, waves diverging from A are made to converge at A_1 . In the same way, we may think of the waves as diverging from A_1 and converging at A . Also waves diverging from B are made to converge at B_1 , or diverging from B_1 to converge at B . AB and A_1B_1 are located at conjugate foci of the lens. If the object is at AB , the image is formed at A_1B_1 , and conversely, if the object is at A_1B_1 , the image is formed at AB .

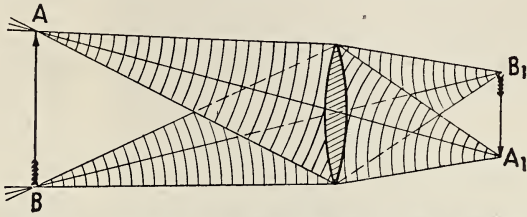


Fig. 335. Diagram showing divergent waves changed into convergent ones through the use of a convex lens.

Graphical construction of an image. In our study of the changes produced by lenses in the light passing through them and the formation of images, we have used light waves. The graphic construction of images is simplified by the use of the rays or the lines showing the direction of the advance of the waves. The diagram in Figure 336 helps to illustrate this. The vertical lines to the left of the lens represent the wave fronts. The horizontal lines represent the rays. As we have learned, the plane waves are changed to converging waves so that the parallel horizontal lines or rays are refracted or bent by the lens into lines or rays that are converging to the point F .

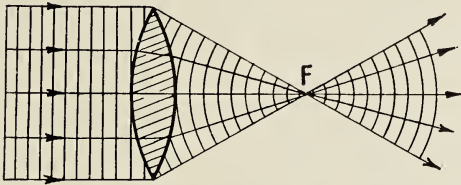


Fig. 336. Diagram showing how a lens causes parallel rays of light to converge to a principal focus.

Definition of terms used in connection with lenses. Before going further into the location of images by the ray method, let us

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define certain terms we shall need to use later. The point O in Figure 337 is called the optical center of the lens. It is the point

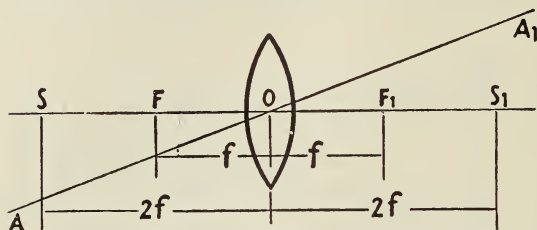


Fig. 337. Diagram illustrating the various factors in the behavior of light when it passes through a convex lens.

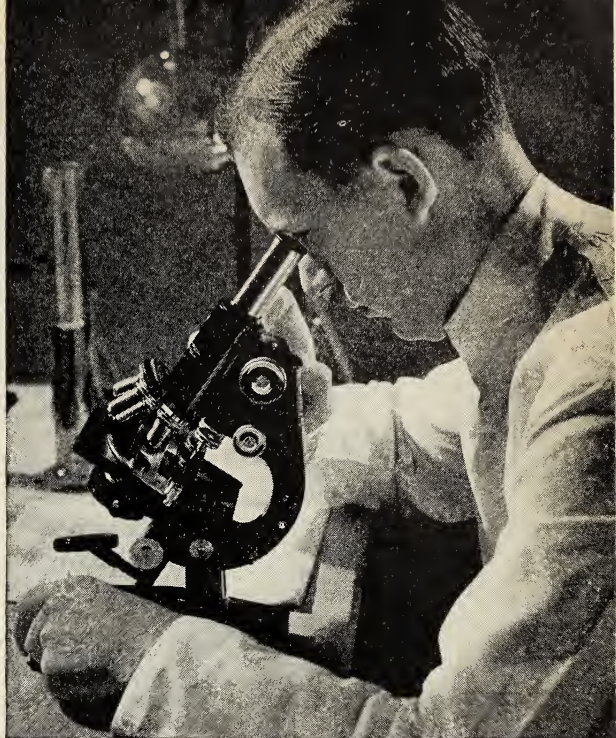
through which a ray may pass without being refracted. The points F and F_1 are called the principal foci, and are the points to which the parallel rays converge after passing through a convex

lens. They are on the side opposite to the source of light. In a concave lens, the principal foci are points from which the rays of light seem to diverge after passing through the lens. They are on the same side of the lens as the source of light and are virtual foci. The focal length of a lens is the distance from the optical center to the principal focus and depends upon the index of refraction of the lens. The greater the index of refraction of the lens, the shorter the focal length. The thicker the lens, the shorter the focal length. Centers of curvature are the points that are the centers of the intersecting spheres that form the double convex and double concave lenses. In a double convex or a double concave lens whose index of refraction is about 1.5, the centers of curvature and principal foci are nearly at the same points, and focal length and radius of curvatures are equal. In a lens with one surface plane and the other surface convex or concave, the focal length is double the radius of curvature of the curved surface. The principal axis of a double convex or concave lens is the line joining the two centers of curvature. It passes through the optical center.

In Figure 337 the line SOS_1 is the principal axis. The points S and S_1 are called the secondary foci. Their distance from O is twice the focal length. Of course, S and S_1 are conjugate foci. Why are they? A secondary axis is any line through the optical center of the lens, but not through the center of curvature. The line AOA_1 is a secondary axis.

How to locate an image by the ray method.

In Figure 338, AB is the object. Spherical waves are sent out from every point on the object, and some of the waves that are passing through the lens are made to converge to a point on the opposite side of the lens. This point of convergence of the waves is the image of the point of source. A spherical wave has innumerable rays, many of which pass through the lens and are converged to one point. Of these many rays from a certain point, as A on the object, two may be selected whose paths through the lens are known. One of these rays, AC , is parallel to the principal axis. Since all parallel rays are refracted by the lens so as to pass through the principal focus F_1 , the line CF_1 is drawn and prolonged. Another ray AO is drawn from A through the optical center O . Any ray passing through the



Ewing Galloway

Scientists use microscopes to procure images of substances or minute organisms that would otherwise not be available for study.

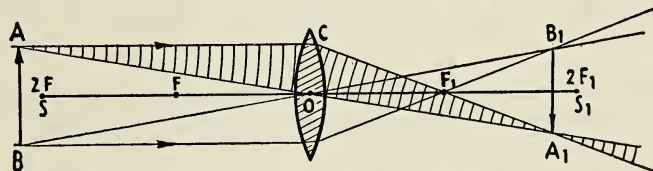


Fig. 338. Drawing showing how an image is located by the ray method. The lens causes the waves to converge and form an image as they converge.

optical center is not refracted. Hence the line OA is prolonged until it intersects the line CF_1 . The point of intersection, A_1 , is the image of A .

The image of any other point on the line AB can be located in a similar way. It is sufficient to locate the images of points

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A and B at the extremities of the object. The line A_1B_1 in Figure 338 is the image of AB . If we examine the drawing further, we find that, while the object is farther from the lens than $2f$, its

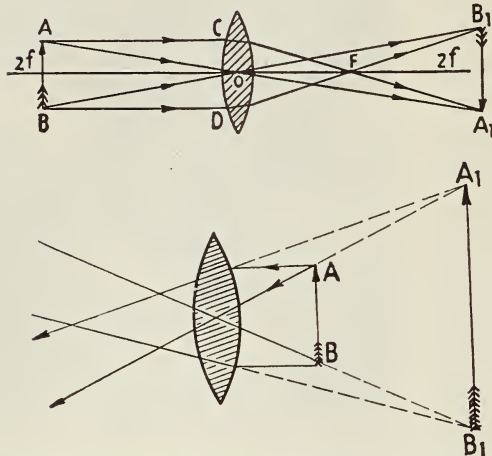


Fig. 339. Diagrams showing how objects at various distances are located by rays passing through convex lenses.

image is nearer than twice the focal length, or $2f$, from the lens. The image is real, inverted, and smaller than the object. When the object is $2f$ distance from the lens, the image is $2f$ distant from the lens and is a real, inverted image the same size as the object.

When the object is less than $2f$ from the lens, as shown in the upper drawing in Figure 339, the image is

more than $2f$ distant from the lens. It is a real, inverted image, and larger than the object. When the object is nearer the lens than the focal distance, as shown in the lower drawing in Figure 339, the image is on the same side of the lens as the object. It is a virtual, erect image, larger than the object.

Location of the image in double concave lenses. Figure 340 is a diagram showing the formation of a virtual image in a double concave lens. The method of locating the image is the same as the one used for a double convex lens. A double concave lens, no matter where the object has been placed, always forms a virtual, erect image that is smaller than the object.

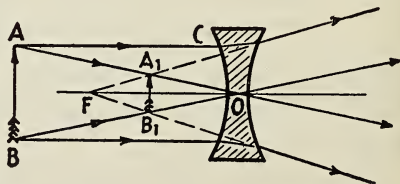


Fig. 340. Rays passing through a double concave lens to form a virtual image.

REFRACTION OF LIGHT WAVES

What determines whether an image is larger or smaller than the object? It may be shown that the relative sizes of the object and

its image depend upon their respective distances from the lens. The upper drawing in Figure 341 represents an image seen through

a convex lens and the lower drawing an image seen through a concave lens. In both these drawings the

triangle AOB is similar to the triangle A_1OB_1 . Therefore

$\frac{A_1B_1}{AB} = \frac{OB_1}{OB}$. Here A_1B_1

is the length of the image

L_i , and AB is the length of the object L_o . OB_1 is the

distance of the image from the lens, and OB is the distance of

the object from the lens. Then the equation is written: $\frac{L_i}{L_o} = \frac{D_i}{D_o}$.

The ratio $\frac{L_i}{L_o}$ is known as the linear magnification of the lens.

It can be shown in a similar manner that the above equation is true for all images produced by lenses.

The image is larger than the object when it is farther from the lens than the object. It is smaller when closer to the lens than the object. Whether the image is nearer to or farther from the lens than the object is determined by the changes produced on the curvature of the light waves by the lens. These changes produced by the lens are expressed by the equations derived in preceding paragraphs. For convex lenses, the following equation

holds: $\frac{1}{D_o} - \frac{1}{f} = -\frac{1}{D_i}$. For real images the equation can be written:

$\frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{f}$. For virtual images the equation becomes: $\frac{1}{D_o} - \frac{1}{D_i} = \frac{1}{f}$.

For concave lenses the equation is as follows: $\frac{1}{D_o} + \frac{1}{f} = \frac{1}{D_i}$. If

two of the three values in any of the foregoing equations are

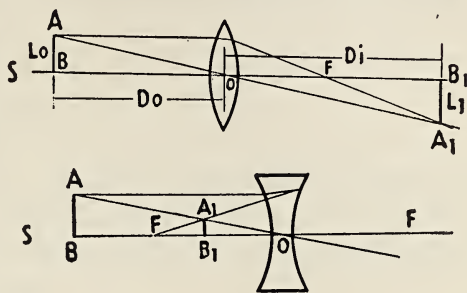


Fig. 341. Drawings showing the relationship between the size of the object and its image.

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known, the third can be found. The following problem and solution illustrate the application of the lens equation.

Problem. How far from a double convex lens, whose focal length is 10, will a real image be formed if the object is 15 centimeters from the lens?

Solution. Equation: $\frac{1}{D_o} - \frac{1}{f} = -\frac{1}{D_i}$, or $\frac{1}{15} - \frac{1}{10} = -\frac{1}{X}$.

Then, $X = 30$ centimeters.

The spherical aberration for lenses. Thus far in our study of the double convex lens, we have assumed that all parallel rays are refracted to a point, but this is not true. The parallel rays that

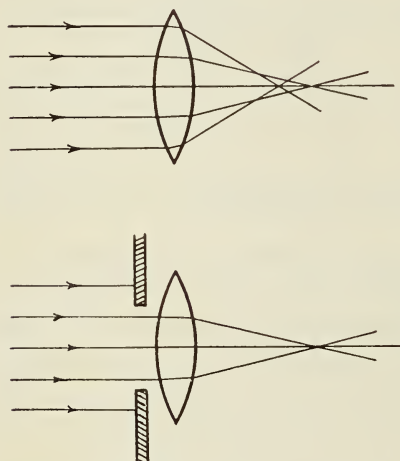


Fig. 342. Refraction of light rays at the edges of lenses is greater than at the center.

pass through the edge of a lens, as shown in the upper drawing in Figure 342, are refracted more than those passing through the center. The rays from the edges cross the principal axis nearer the lens than those nearer the center, and a sharp focus is not obtained. This causes a blurring of the image. This feature of the lens is called spherical aberration. Spherical aberration may be remedied by cutting off the rays nearer the edge by a diaphragm as shown in the lower drawing in Figure 342. This, of course, cuts out a part of the

light. In order to prevent spherical aberration, lenses are ground so that the curvature is less at the rim than at the center.

ANSWER THESE QUESTIONS

1. What is the principal difference between a mirror and a lens?
2. What effect is produced upon plane waves when they pass through a convex lens?

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3. What effect is produced when plane waves pass through a concave lens?
4. Does a convex lens produce convergent or divergent waves of light?
5. What is meant by the following terms: optical center, principal focus, focal length, center of curvature, and principal axis?
6. What determines whether an image is larger or smaller than the object?
7. What determines whether an image is inverted or erect?
8. How are lenses made in order to prevent spherical aberration?

SOLVE THESE PROBLEMS

1. The focal length of a double convex lens is 10 centimeters. When an object is placed 16 cm. from the lens, what distance from the lens is the image?
2. A candle is placed 20 cm. from a double convex lens. Its image formed on a card is 80 cm. from the lens. Find the focal length of the lens.
3. The image of an object 4 in. long is formed on a screen by a lens whose focal length is 6 inches. If the image is 16 in. long, how far away is the screen? How far from the lens is the object?
4. A double convex lens whose focal length is 15 cm. forms an image on a screen 60 cm. away. If the object is 10 cm. long, what is the length of the image?
5. The focal length of a double concave lens is 6 centimeters. An object 8 cm. long is 10 cm. from the lens. What is the apparent location of the image, and what is the apparent size?
6. The focal length of a double concave lens is 12 centimeters. If an object 4 cm. long is placed 10 cm. from the lens, what is the apparent location and the apparent size of the image?

AREA FIVE

How Are the Principles of the Lens Illustrated in Vision and in Optical Instruments?

Already in various health courses we have studied such topics as the following: the structure of the eye, the eye as a camera, near-sightedness and farsightedness, the use of eyeglasses to correct defective vision. In this area we shall study similar topics from

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the standpoint of physics, applying principles of reflection, refraction, and other important principles. Besides studying the eye, we shall study numerous instruments used in connection with the transmission of light, such as the camera, optical lenses, and optical instruments.

THE EYE AND THE CAMERA

How we see through the eyes. When light enters the eye from an object, it passes through the refracting media cornea, aqueous humor, crystalline lens, and vitreous humor, as shown in Figure 343. These media, principally the crystalline lens, bring the

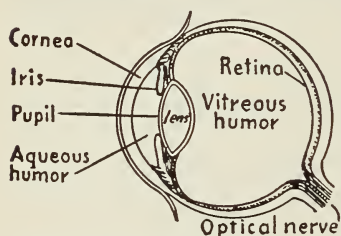


Fig. 343. Cross-section diagram of the human eye, showing various parts.

light to a focus on a screen, known as the retina, at the back of the eye. The image formed on the retina is inverted and smaller than the object. Since the image is inverted, the eye actually sees things upside down. The nervous system, however, interprets the image so that we sense the true position of the object. Likewise, although the image on the retina is much smaller than the object, the nervous system enables us to sense the size of the object. The crystalline lens, which brings the rays to a focus, changes in convexity on the basis of distance from the object. The ability of the lens to change convexity so that we may see objects both near and far is called the power of accommodation.

The duration of vision. A visual impression lasts about one-sixteenth of a second. A person seems to see light about one-sixteenth of a second after it has gone. Thus a rapidly revolving wheel seems to form a solid wheel, and a rapidly swinging lantern at night seems to form a solid ring of light. Distinct impressions cannot be made of separate events unless the events succeed one another at greater intervals than one-sixteenth of a second. It is this duration of the visual impression of fast-moving objects that gives the illusion of motion pictures.

THE LENS IN VISION AND OPTICAL INSTRUMENTS

How we judge the size and distance of objects. The rays of light from the extremities of each object that we see form an angle intersecting at the eye, as the $\angle AEB$ in Figure 344. This is called the visual angle. The size of this angle depends upon the size of the object and its distance from the eye. The apparent size of a body depends upon the visual angle, because the angle determines the size of the image on the retina. In Figure 344, the two objects AB and A_1B_1 are of equal size. AB appears larger to the observer, however, because the rays from its extremities, AE and BE , form a larger angle, AEB , than those from the object, A_1B_1 . Hence a larger image is formed on the retina.

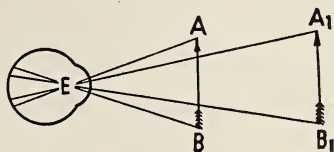


Fig. 344. Angles of rays from objects intersected at the eye.

In judging distance we are helped by the slight turning in of both eyes, depending on the nearness to the object. Thus muscular control of the two eyes working together enables us to judge how far away an object is. If we close one eye and try to judge distance with the other eye, we are handicapped because the muscles of both eyes are accustomed to working together.

Distance of distinct vision. From the foregoing explanation of how we judge size and distance, we might think that the nearer we bring an object to the eyes, the more distinct the object becomes, but such a conclusion is true only within certain limits. If we hold a book at arm's length and then bring the book gradually nearer, we find that the print becomes distinct up to a certain point. If we continue to bring the book nearer from this point, the print gradually becomes blurred and finally so blurred that we cannot read it. The distance at which we can see an object best is called the distance of distinct vision. This distance varies with different people, but 10 inches, or 25 centimeters, is the average for normal eyes.

Why some people must wear glasses. As already explained, the lens in the eye changes its curvature according to the distance to

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the object, so that a correct image will be reflected on the retina. When the eyes are unable to make this accommodation, special lenses must be used to supplement the lenses in the eyes and direct the light rays properly to the retina. Three kinds of defective vision usually require the use of glasses: (1) nearsightedness, myopia; (2) farsightedness, hypermetropia; (3) astigmatism.

Nearsightedness. The nearsighted eye is one in which the eyeball is too long. The upper drawing in Figure 345 illustrates the shape of the normal eyeball, and the middle drawing illustrates the shape of the eyeball that causes nearsightedness. In this case the lens focuses the waves of light coming from objects before they reach the retina. However, light coming from an object very near is focused on the retina. Persons

Test to show whether the use of eyeglass lenses is necessary in this case for right vision.

Ewing Galloway

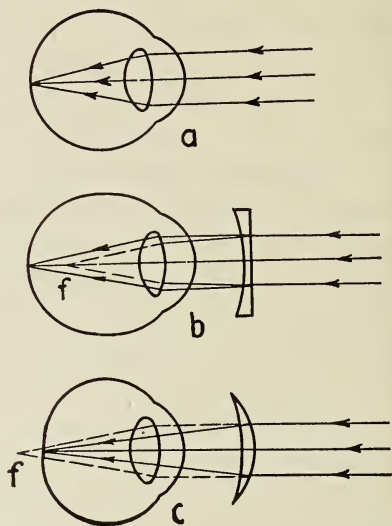
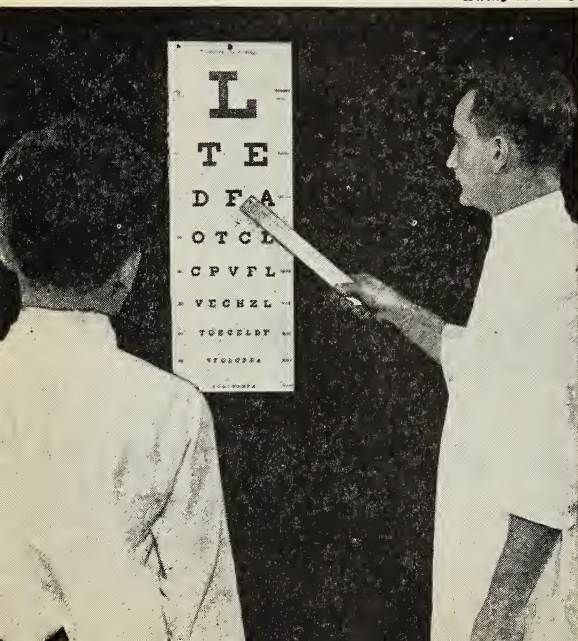


Fig. 345. Different types of lenses that help to remedy physical defects in the human eye.

having such eyes are said to be nearsighted because they must bring the object very close to see it distinctly. A concave lens corrects nearsightedness, since it causes the entering waves to diverge and hence to come to a focus farther back.

Farsightedness. In the lower drawing, Figure 345, the eyeball is too short. The light from near objects is focused too far back, and the image

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forms behind the retina. Persons who see objects clearly at a distance but not close to them are said to be farsighted. The remedy is to make the incoming waves convergent, so that the crystalline lens forms an image close enough to fall on the retina. Convex lenses are used in such cases. In old age, farsightedness occurs because the crystalline lens gradually loses some of its elasticity and becomes more rigid. Consequently the lens will not become convex enough to focus waves whose convexity is great because of the short distance from the object to the eye.

Astigmatism. Astigmatism is due to irregularities in the shape of the eyeball, especially in the curvature of the cornea, or a lack of symmetry in the crystalline lens. This causes a distortion of the image on the retina. The extent of astigmatism may be determined by a glance at the radiating lines shown in Figure 346. If the defect is present, the radiating lines will not be seen with equal distinctness. Astigmatism may be corrected by specially ground lenses that will compensate for the defects in the curvature of the parts of the eye.

Why spectacle lenses are curved. You will notice that the lenses in glasses, whether thicker in the middle or thinner in the middle, are convex on one side and concave on the other. They are called meniscus lenses. Other lenses, that is, the double convex, the plain convex, the double concave, and plane concave, are called flat lenses. If flat lenses were used, the wearer would need to move his head up or down or sideways to see objects clearly. With the meniscus-type lens a fairly wide range of vision is afforded with no turning of the head.

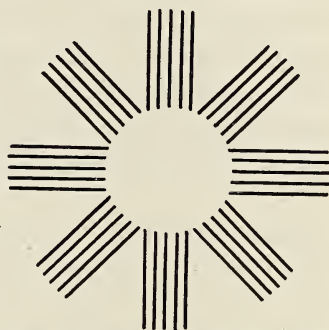
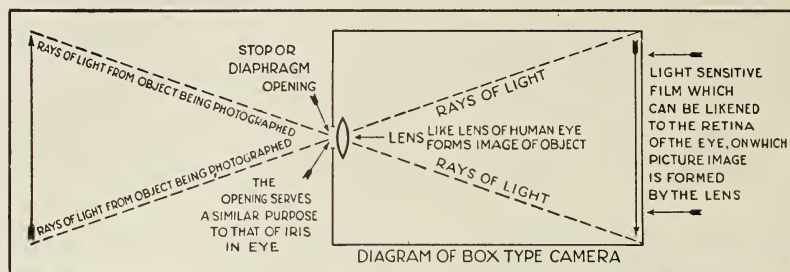


Fig. 346. Defects in curvature of the eye make some lines appear blacker.

The camera. The camera as we know it is very much like the eye. It consists of a sensitive screen on which the image is formed just

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as it is formed on the retina. It has a lens, as shown in Figure 347, or a combination of lenses that acts like the crystalline lens of the eye. It differs from the eye in that a permanent image is



Courtesy Eastman Kodak Co.

Fig. 347. Similarities between the parts of the human eye and those of an ordinary box-type camera. Differences between the eye and the camera make the photographic record of a camera more reliable in many ways than the images formed by the eye.

formed on the plate or film. In the camera a real, inverted image is formed, smaller than the object. A diaphragm regulates the amount of light that enters the camera, just as the iris regulates the amount of light that enters the eye. The shutter excludes light, just as the eyelids do. However, the camera also differs from the eye in that it is not self-focusing.

Evidence given by the camera. The iris automatically regulates the amount of light, but the operator of a camera must learn by experience how the amount of light is to be regulated. However, the camera has the advantage over the eye in that it gives an exact picture of what is happening at the time the picture is taken, with details that the eye does not catch. What a person sees is always modified by former experiences, so that he does not always see what he thinks he sees. For this reason motion pictures are much more reliable evidence of what occurred than what observers can see. Football coaches use such pictures to study what each player has done in a game. Motion pictures of horse races offer evidence to settle doubtful questions.

In order to take satisfactory pictures, a person must have a camera with suitable lenses. Among other things, the lenses

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must be free from the qualities that cause spherical and chromatic aberration. Spherical aberration is overcome by means of a diaphragm that shuts out the light from the outer edges. Chromatic aberration is overcome by means of an achromatic lens, or a lens with two different indexes of refraction.

Aerial photography. The war has given great prominence to aerial photography. Pictures taken from airplanes of battles at sea, on the land, and in the air are printed in the newspapers and magazines. In military service, aerial photography is being used extensively for reconnaissance and map making and is of primary importance in planning campaigns.

Photographs taken from the air are either oblique photographs or vertical photographs. An oblique photograph is taken with a camera held so that its longitudinal axis makes an angle of less than 90° with the horizontal plane of the ground. It is usually taken with the camera held over the side of the airplane or suspended from it. An oblique photograph can be taken best after the airplane has passed the object and the photographer can look back at it. The photographer must have a well-trained judgment for perspective, balancing, lighting, and background. A good oblique aerial photograph does not depend alone on the skill of the photographer, however. It depends very much on the skill of the pilot in handling the airplane. He too should understand the problems of exposure, perspective, lighting, and background, so that he may handle his airplane to put it in the best position for taking the photograph.

A vertical photograph is taken with a camera pointed at the earth, so that its longitudinal axis is perpendicular to the plane of the earth or as near 90° as possible. The camera is usually mounted inside the fuselage of the airplane with its lens pointing through an opening in the bottom of the airplane. The principal use of vertical aerial photography is in the making of maps. When a composite picture of a certain area is desired, a sufficient number of aerial photographs are combined to form an aerial photographic mosaic. The making of a mosaic involves flying

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back and forth across the selected area and taking aerial photographs in both directions, in order to obtain pictures that will overlap in all directions. A constant altitude must be kept and the camera must be reasonably level at the time of exposure.

The following questions must be considered in taking vertical aerial photographs: (1) What is the area of surface that is to be included? (2) What type of camera should be used? (3) At what altitude should the airplane fly? (4) What will be the scale of the photographs taken at a certain altitude?

Cameras used in aerial photography. Space will not permit a full description of different types of cameras used in aerial photography. Only a general description pointing out some characteristics can be given. There are two standard types, the single-lens

Overlapping photographs taken by vertical aerial photography are put together to make a composite picture of a lake-strewn farming region as shown below.

Paul Photos



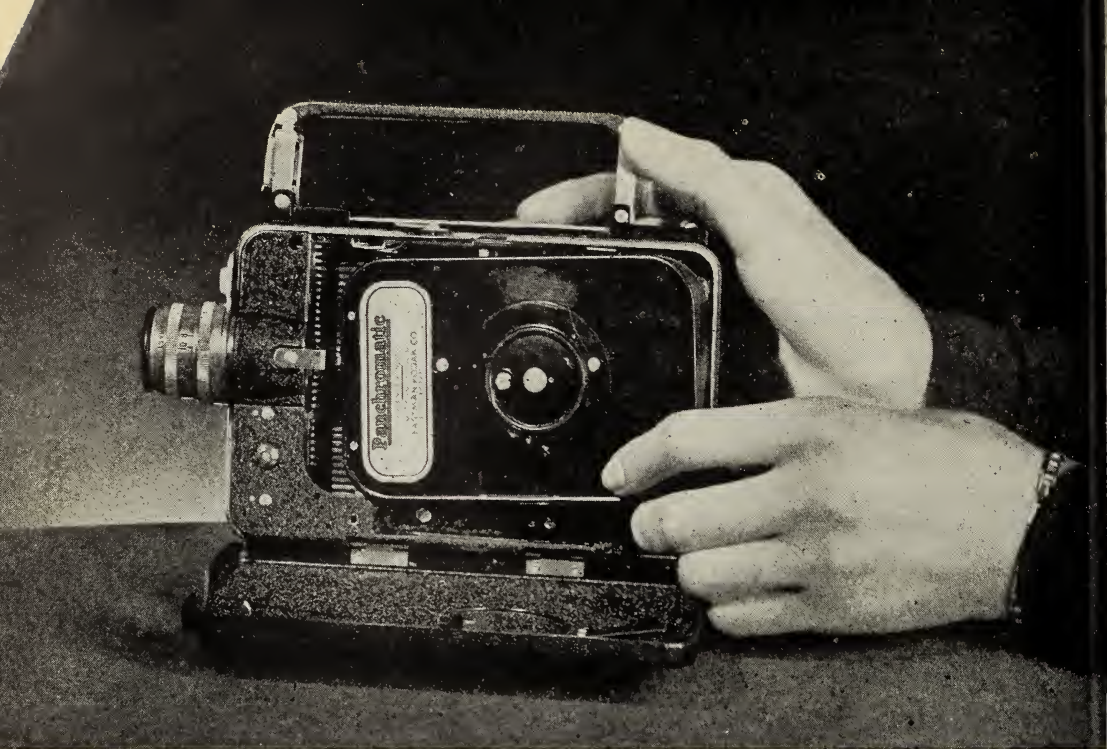
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cameras and the multiple-lens cameras. Aerial cameras are mostly fixed-focus type; an adjustable focus is not necessary because the photographs are taken from great heights. However, for taking oblique pictures cameras with adjustable lenses are sometimes used. Aerial cameras are made of a light metal, such as duraluminum, that also has the capacity to stand up under hard usage.

To neutralize the vibration of the airplane, the camera is either suspended in a mounting that has its point resting upon sponge rubber, or it may be suspended by rubber cords to minimize the effects of vibration. Cameras used for vertical photography have a gimbal mounting that permits the camera to incline freely in any direction and thus to maintain a position perpendicular to the earth's surface under any condition of flight.

The camera sight, or view finder. The camera sight, or view finder, is an arrangement used by photographers to make sure the object desired is being photographed. In oblique cameras the sight is usually a negative lens attached to one side of the camera near the rear end. The lens is so ground and is of such size as to show the exact area covered by the lens. Vertical aerial cameras have a separate sighting device or view finder. This consists of a tapering metal box about 8 inches long that is essentially a small fixed-focus camera. Some vertical cameras have an operating mechanism that trips the shutter and spaces the film. A timing device for tripping the shutter at predetermined intervals, calculated with reference to ground speed and the altitude at which the airplane is flying, is used on such cameras. This timing device is called an intervalometer.

The projection lantern is a camera in reverse action. The projection lantern is much like a camera, except that the object and the image are interchanged. The lantern consists of two optical systems. One, called the condensing lens, concentrates the light upon the slide. The other consists of a combination of lenses that acts as a single converging lens called the objective, the function of which is to focus the light on the screen. The object



Courtesy Eastman Kodak Co.

In this picture a roll of film is being placed in a motion-picture camera of a type that is compact and simplified in operation for use by the amateur photographer.

is a transparent slide on which is the picture to be shown upon the screen. Because the image on the slide is inverted, the slide is inverted, so that the picture appears on the screen in normal position. In order that the picture may focus clearly on the screen, the screen and slide must be at conjugate foci. Lanterns, like cameras, are so made that the objective can be moved until at the proper distance from the slide to throw a clear image on the screen.

Because the image is enlarged so much, the slide must be very strongly illuminated. This is accomplished by the use of a lamp of very high candle power. Formerly, arc lamps were used, but an incandescent lamp of great luminosity is now more common. A concave spherical mirror is placed behind the lamp to increase the intensity of the light on the condensing lens. The two large-diameter plane convex lenses that form the condensing lens are placed at about the focal length of the combination in front of the lamp to intensify the illumination of the slide.

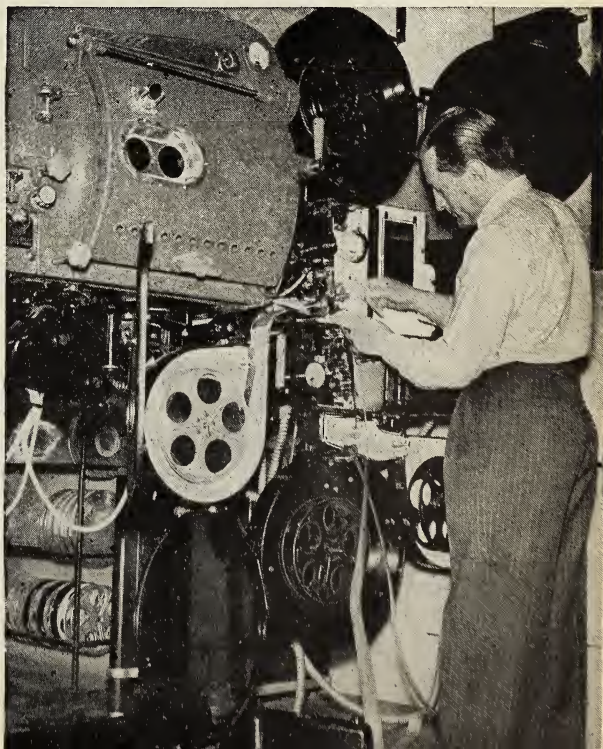
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Taking motion pictures. In the preparation of motion pictures, a camera is used which takes a series of pictures on a film that is moved by jerks. While the film is moving, a shutter, which operates mechanically, shuts off the light from the lens at intervals. The movement of the shutter is so timed that it opens while the film is stationary, and a picture is taken. The camera mechanism is operated so that about 16 pictures per second are taken. The films are wound into reels of about 1000 feet each, and one foot of film moves past the lens every second.

Showing the pictures. Motion pictures are projected by a lantern that does not differ materially in principle from the projection lantern already described. However, in place of slides, a roll of film is used. This is unwound from one reel and wound upon another. Each picture comes to a complete stop while it is being shown. Then it moves on, and another takes its place. A revolving shutter is used to cover the picture while it is in motion. We see a series of separate pictures, which succeed one another at the rate of 16 or more per second. To us, however, these pictures do not appear as 16 separate pictures, but as one continuous picture. This is because of the duration of vision already described. Each picture persists in our brain for about $\frac{1}{16}$ of a second after it is gone. We are still seeing the last picture when the succeeding one appears, and so they all blend into one continuous picture. As each picture shows an object in a little different position, we seem to see the motion that produced this difference in position.

The projectionist threads the films into the projection machine to give the director a preview of the results of the day's work in motion-picture photography.

Ferdinand Hirsh



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Pictures in which we not only see people moving but hear them talking—sound pictures. In all methods used to produce talking pictures, the microphone is used to change sound waves into varying currents that are amplified. In some methods the sound record is put on the picture film in a narrow band near one edge of the film. In one process the band consists of a series of striations of varying density. In another process the band is of constant density but of variable width.

The band of variable density is produced by exposure of the film to a glow lamp whose brightness is varied by the amplified electric current that comes from the microphone. The brightness of the lamp follows, in its intensity and frequency, the intensity and frequency of the current. The exposure at any one place, and hence the blackness of the film, varies with the brightness of the lamp. This produces a track of varying density. In another method the sound record is made on the film by amplification of the current from the microphone so that it can control the width of a slit (light valve) through which light from a lamp is focused on the film. Therefore, as the current varies, the amount of light focused on the film varies and a track of variable density is produced. The track of variable width is produced by a small spot of light from a mirror focused on the film. This mirror is made to oscillate by the amplified microphone currents and thus to produce a track of variable width. The sound is reproduced from both the variable-density and the variable-width sound tracks in the same way. Light is focused on the sound record and affects a photoelectric cell placed on the other side of the film. The varying light from the film sets up in the cell a varying current that is amplified and goes to the loud speaker.

THE MICROSCOPE

The simple magnifier. Lenses are used to make visible what our unaided eyes cannot see. One of the simplest magnifying devices is the familiar magnifying glass, or the simple microscope. This is generally a double convex lens. The object is placed at a distance less than the focal length of the lens, so that an erect, enlarged

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image is produced. We have learned that the apparent size of a body depends upon the visual angle. Its apparent size grows larger as it is brought nearer the eye because its visual angle is enlarged. But the eye does not form a clear image of an object brought nearer than 25 centimeters or 10 inches. The lens enables the eye to form images of objects closer than 25 centimeters.

By use of the lens, an image can be brought much closer to the eye. Therefore the visual and apparent size of the object is greatly increased, as shown by Figure 348. AEB in the upper drawing is the visual angle subtended by the object when it is 25 centimeters from the eye. A_1OB_1 in the lower drawing is approximately the visual angle made by the object when a lens is used. The ratio of A_1B_1 to AB is the magnification. A_1B_1 is the length of the image, L_i , and AB is the length of the object, L_o . Then the magnification is $\frac{L_i}{L_o}$. But, as we have learned, $\frac{L_i}{L_o} = \frac{D_i}{D_o}$. In the above figure D_i is taken as the distance of most distinct vision—that is, 25 centimeters—and D_o is approximately the focal length of the

lens. $\frac{D_i}{D_o}$ becomes $\frac{25}{f}$, which is the theoretical magnification of a simple microscope. This is the magnifying power of a simple lens used as a magnifying glass.

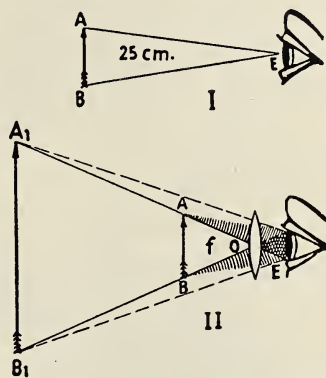


Fig. 348. The above drawings show the magnification of an object made possible by the use of a simple microscope.

The compound microscope. A compound microscope has two systems of lenses. The lower lens system, which is near the object, is called the objective. It forms a real, enlarged image of the object. This image is located at a distance very little less than the focal length from the upper system, called the eyepiece. The eyepiece, since the object distance D_o is less than the focal length, forms a magnified virtual image of the real image formed by the objective.

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The eyepiece functions as a magnifying glass, and its magnification is $\frac{25}{f}$. The object is generally just beyond the focal length of the objective. From the equation $\frac{L_i}{L_o} = \frac{D_i}{D_o}$ we see that $\frac{D_i}{D_o}$, that is, the ratio of the image distance to the object distance, represents the magnification of the objective. Therefore the magnification of a compound microscope is represented by the equation $M = \frac{D_i}{D_o} \times \frac{25}{f}$. A compound microscope that will serve for a laboratory experiment can be constructed of two convex lenses of short focal lengths mounted on a ring stand, as shown in the left-hand diagram in Figure 349. The left side of this diagram

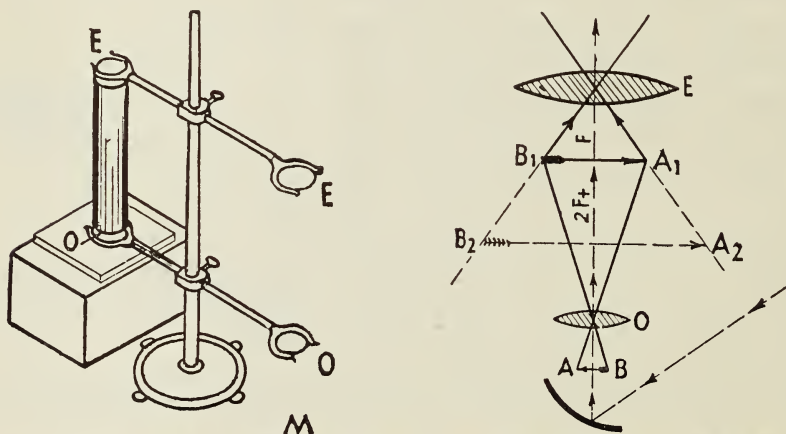


Fig. 349. At the left in the above drawing is shown a compound microscope made of two mounted convex lenses of short focal length. At the right is shown the relative positions of the object and its image and the degree of magnification of the object.

shows how a tube and platform may be added to make the microscope more nearly like the regular laboratory instrument. Place an object at M , and lower lens O until the object is just outside of its focus. Move lens E up or down until a clear magnified image is seen. The drawing at the right in Figure 349 shows the relative positions of an object AB , the real image A_1B_1 , and the virtual magnified image, A_2B_2 , of the real image.

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In high-powered, compound microscopes the objective system consists of a combination of many lenses, as shown in Figure 350. In such instruments the focal lengths of the objective and eyepiece are very short. Hence the object distance D_o is taken as the focal length of the objective, and the image distance D_i as the distance between the objective and eyepiece (or length of tube, L) without an appreciable error. Then the magnifying power is expressed by the equation

$$M = \frac{L}{F} \times \frac{25}{f},$$

in which L is the length of the tube, F the focal length of the object, and f the focal length of the eyepiece. When 25 is used, the other factors L , F , and f are in centimeters. When these factors are expressed in inches, the constant 10 inches must be used in the equation. We increase the magnification of a compound microscope by increasing the length of the tube, and by using lenses for the objective and eyepiece whose focal lengths are as small as possible.

Example. A compound microscope has, for an objective and for an eyepiece, lenses whose focal lengths are 5 millimeters each and a tube 15 centimeters long. Find its magnification.

Solution. Since $M = \frac{L}{F} \times \frac{25}{f}$, then $M = \frac{15}{0.5} \times \frac{25}{0.5} = 1500$ diameters (magnified 1500 times).

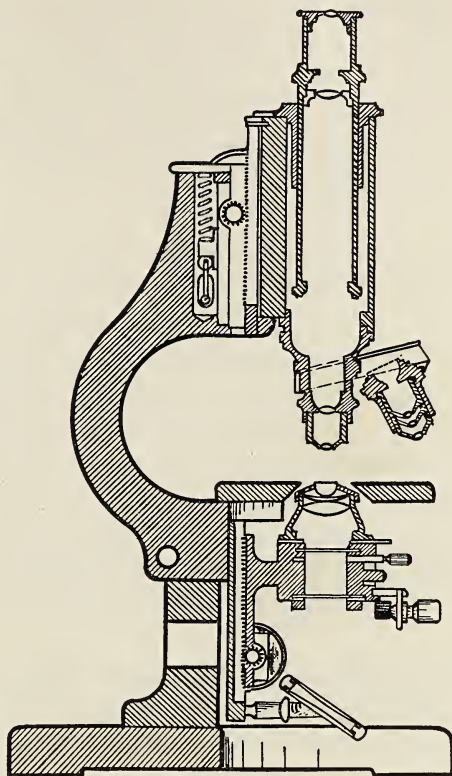


Fig. 350. A compound microscope such as the one shown here has many lenses and adjustment devices.

EXPLORING THE UNIVERSE OF LIGHT ENERGY

THE TELESCOPE

The telescope is a device in which lenses are used to enable us to see distant objects. In 1609 Galileo made a telescope that magnified 30 times. With it he made many discoveries while examining the heavens. Today the largest refracting telescope in the world is at the Yerkes Observatory of the University of Chicago, at Williams Bay, Wisconsin. It has an objective lens 40 inches in diameter mounted in a tube 63 feet long. The lens itself weighs 760 pounds.

The refracting telescope. The refracting telescope consists of an objective producing a real image of a distant object, and an eyepiece, which is a magnifying glass, producing a magnified image of the image formed by the objective. The difference between a telescope and a compound microscope is that the objective of the microscope produces a magnified image of the object, while the objective of the telescope produces a diminished image. But in the telescope this image is very bright. The image is made bright by the use of a lens of large diameter for the objective. The large lens gathers a great many rays and focuses them to form the image.

The astronomical telescope. The principle of the astronomical telescope is shown in Figure 351 by two lenses mounted on a meter stick, with a cardboard screen mounted between them. One of the lenses should have a comparatively long focal length

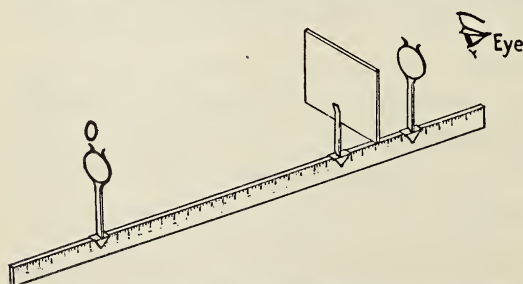


Fig. 351. Drawing showing the construction of an astronomical telescope for simple laboratory experiments.

of 35 to 50 centimeters. This lens is the objective. The focal length of the other lens is about 5 centimeters. The distances of the lenses from the cardboard are so adjusted that each forms a real image on the

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cardboard. When the cardboard is removed, we have a telescope. We can test its magnifying power by drawing two lines about 5 centimeters apart on the blackboard. Looking through the telescope with one eye, and at the blackboard with the other eye, we draw two more lines on the blackboard, showing the apparent distance between the first two lines drawn. By comparing their apparent distance with their actual distance apart, we find the magnification, or $\frac{L_i}{L_o}$. The eye, looking

through the lenses, sees a virtual magnified image of the real image. In the upper drawing in Figure 352, A_1B_1 is the real image and A_2B_2 is the magnified image. Such a telescope, of course, gives an inverted image. For astronomical observations this does not matter. This is called an astronomical telescope.

Terrestrial telescopes. For use in looking at bodies on the earth, a special lens is inserted to reinvert the image before we look at it with the eyepiece. Such a lens is placed at just twice its focal length away. Since this image is also inverted, the eyepiece forms a virtual, magnified image of it, and we see an erect image of the object, as shown in the lower drawing in Figure 352.

The theoretical magnifying power of a telescope is: magnification = $\frac{F}{f}$, in which F is the focal length of the objective and f is the focal length of the eyepiece.

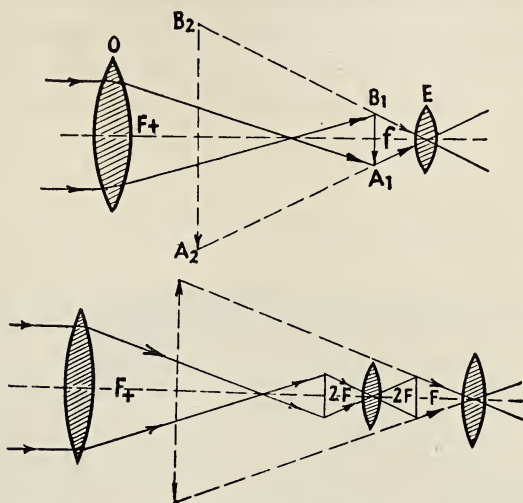


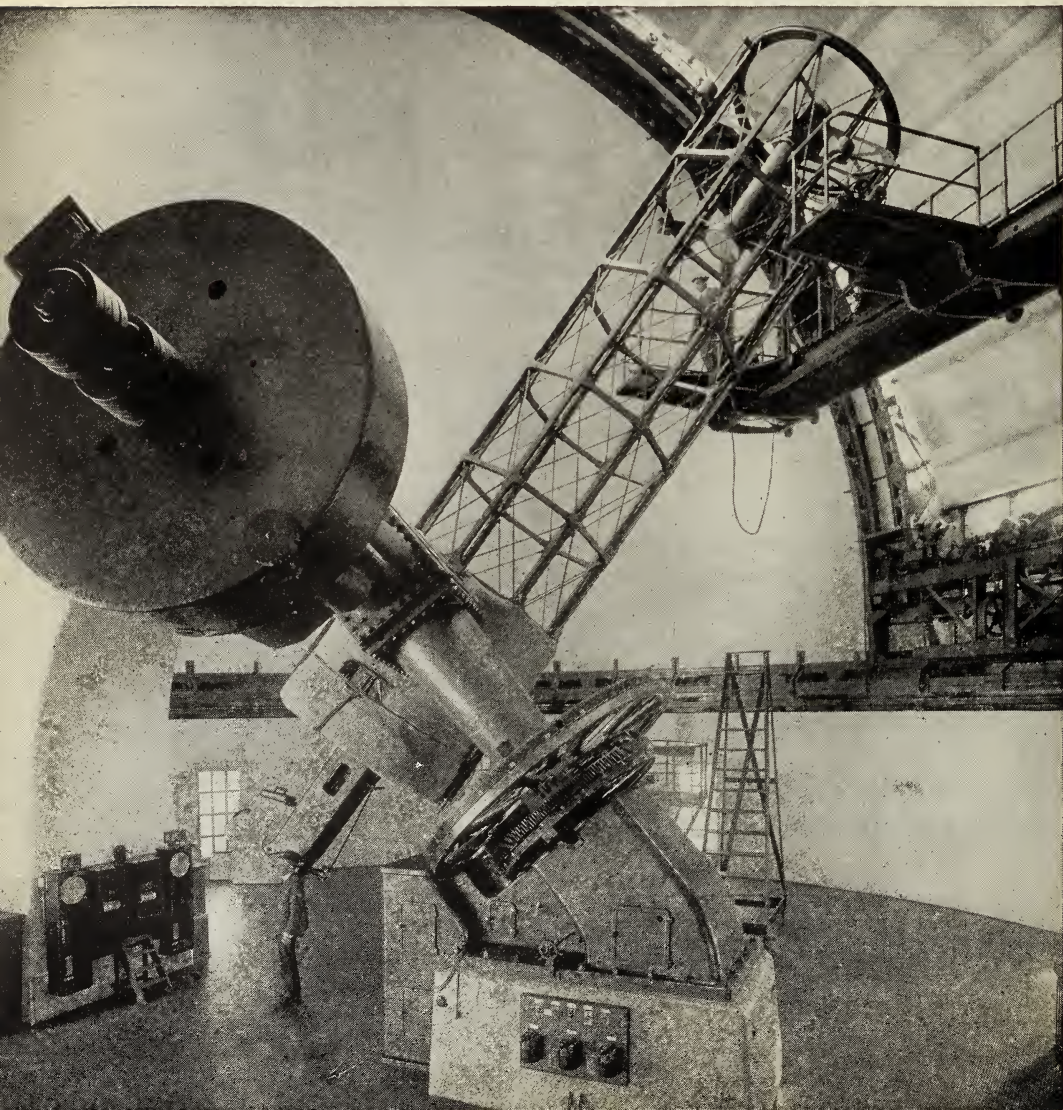
Fig. 352. Diagrams showing the arrangements of lenses and how images are formed in two types of telescopes. In the upper drawing is shown an astronomical telescope, and in the lower drawing a terrestrial telescope.

EXPLORING THE UNIVERSE OF LIGHT ENERGY

Reflecting telescopes. In the construction of telescopes for astronomical observation large mirrors are used instead of the objective lens to form real images. The largest telescopes in the world are of such construction. On Mount Wilson, Pasadena, California, there are two reflecting telescopes, one with a mirror 60 inches in diameter and the other with a mirror 100 inches in diameter. The 60-inch mirror weighs one ton, and the 100-inch four and a half tons. A mirror 200 inches in diameter is completed and is being installed in the observatory of the California Institute of

Huge astronomical telescopes are used in studying the movements of the stars. In such telescopes large mirrors are used instead of the objective lens to form real images.

Courtesy The Warner and Swazey Co., Cleveland, Ohio



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Technology on Mount Palomar, California. The glass of these large mirrors has to be perfectly annealed. The disks were cast and annealed again and again, but each time they broke. At last, after many trials, disks free from strain were produced. After any disk is cast, it has to be ground and polished into a true parabolic form. In these large telescopes the image is usually focused upon a photographic plate. In some the image is viewed by an eyepiece, as in a refracting telescope.

The opera glass. The opera glass, like the astronomical telescope, has an objective and eyepiece, as shown in Figure 353. Unlike the eyepiece of the telescope, however, the eyepiece of the opera glass is a divergent or concave lens. The distance between the

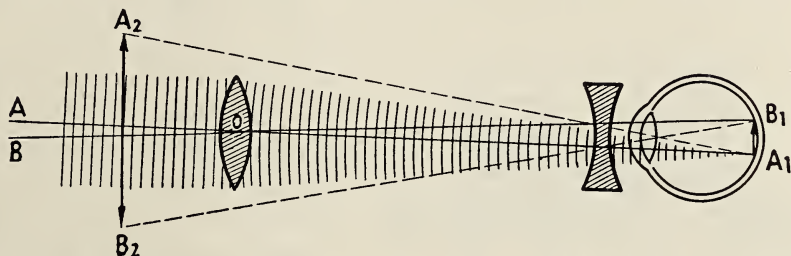


Fig. 353. The above drawing shows an opera glass in which the eyepiece is a double concave lens with a focal length equal to the focal length of the lens of the eye.

objective and the eyepiece is the difference between their focal lengths. The converging rays coming through the objective strike the eyepiece before they are brought to a focus. Since the diverging effect of the eyepiece exactly equals the converging effect of the lens of the eye, the effect is the same as if the objective formed its image directly on the retina. The magnification of an opera glass is expressed in the following equation:

$$M = \frac{\text{focal length of objective } (F)}{\text{focal length of the eyepiece } (f)},$$

which is the same as for an astronomical telescope. Objects seen with an opera glass appear in normal position. This is because the images formed on the retina are inverted, as are the images formed by the lens of the unaided eye. Opera glasses magnify

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only three or four times. They have a very small field of view. Their advantages are that they are short and compact, that they are binocular, and that they transmit normal images. The telescope that was made by Galileo greatly resembled an opera glass, except that it had only one tube.

The prism binocular. The opera glass, because of its shortness, has a small field of view and small magnifying power. The terrestrial telescope has a larger magnifying power and a larger field of view. To gain these advantages, it must be of an inconvenient length. The prism binocular retains both the compactness of the opera glass and the larger field of view of the telescope. It consists of an objective, an eyepiece, and two totally reflecting prisms.

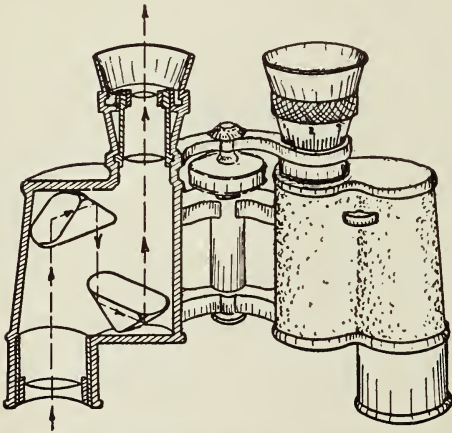


Fig. 354. The prism binocular shown here contains reflecting prisms that invert and reinvert the image.

Figure 354 shows how these reflecting prisms, as the light travels the length of the tube about three times, create the necessary distance between the objective and the eyepiece. The reflecting prisms not only make possible a shorter instrument but, in reflecting the light four times, reinvert the image so that the real image formed in front of the eyepiece is a normal, not an inverted, image.

ANSWER THESE QUESTIONS

1. How do we know that the image on the retina of the eye is an inverted image?
2. Why do distant objects seem smaller than they are, and why do small objects seem more distant than they are?
3. At what distance does the normal eye see best?
4. What type of lens is used to correct nearsightedness?
5. What is the cause of astigmatism?

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6. Why are meniscus-type lenses used in eyeglasses?
7. What would be the result if a motion-picture camera were operated faster or more slowly than 16 photographs per second?
8. How does a simple magnifier such as a reading glass or simple microscope aid the eye in seeing small objects?
9. What is the purpose of each lens in a compound microscope?
10. In what important features does a refracting telescope differ from a reflecting telescope?
11. What are the important differences between an astronomical telescope and a terrestrial telescope?
12. How does the prism binocular combine the advantages of the opera glass and the terrestrial telescope?

SOLVE THESE PROBLEMS

1. A reading glass has a focal length of 5 inches. What is its magnifying power?

2. A photograph of a building 100 ft. away was taken. The plate was one ft. from the lens. What was the focal length of the lens? If the picture is 6 in. high and 8 in. long, what was the height and length of the building?

3. A camera with a lens combination whose focal length is 6 in. is used to take a picture of an automobile 20 ft. away. How far from the film must the lens be set? If the automobile is 15 ft. long, how long is the picture?

4. The slide in a projection lantern is 15 in. from the lens, and the picture is thrown on a screen 40 ft. away. If the slide is 3 x 4 in., what is the size of the picture? What is the focal length of the lens?

5. The tube of a microscope is 18 cm. long. The focal length of the objective is 3 mm., and the focal length of the eyepiece is 2 centimeters. What is its magnifying power?

6. The length of the tube in the microscope, constructed in the laboratory, is 8 cm., and the focal length of the eyepiece is 2 cm. and of the objective 2 centimeters. If the object is placed 3 cm. from the objective, what is the magnifying power of the microscope?

7. The objective of the Yerkes refracting telescope has a focal length of 62 ft., and the focal length of the eyepiece is $\frac{1}{4}$ inch. What is its magnifying power?

8. The parabolic mirror used as the objective in a telescope at Mount Wilson Observatory is 100 in. in diameter and has a focal length of about 50 feet. What magnification is obtained with a one-inch eyepiece? Why is the diameter of the mirror so large?

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AREA SIX

How Are Colors Produced?

The rainbow, though familiar to all of us, is always a source of admiration and wonder, for it is one of the most spectacular of natural phenomena. Color, of course, always attracts attention. Beautiful effects are produced by artistic combinations of colors. The study of color, therefore, is interesting because it helps to explain many of the color phenomena in our own everyday experiences. The scientist has analyzed color, described it in terms of light waves, and measured the wave length for each color. He has discovered many facts that to us seem unrelated to light waves and color. This area includes a discussion of the nature of color and how scientific knowledge of color is put to use.

White light is composed of colors. Throughout this unit we have discussed light waves without reference to colors or lengths of light waves. We have described reflection, refraction, and absorption as if light waves were of uniform character, and this assumption was justified for the problems studied. Now we shall study the light waves themselves to discover how colors are produced. The following experiment shows how the light from the sun may be broken up into lights of different colors. Sunlight shines through a narrow slit and falls upon a triangular prism, as shown in Figure 355. The light refracted by the prism

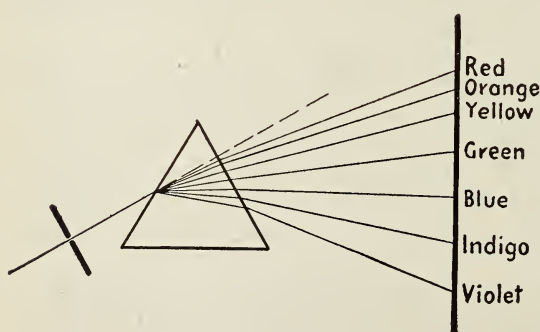


Fig. 355. Diagram showing how sunlight falling on a triangular prism is refracted into waves of different colors.

falls upon a white screen or wall. We see that the light not only is bent aside but is spread out into colored bands that show the colors red, orange, yellow, green, blue, indigo, and violet, in the order shown in the

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drawing. These color bands form what is called the spectrum. The separation of white light into the spectrum is called dispersion.

Cause of dispersion. The foregoing experiment shows that white light is not one wave but a composite of waves of different lengths. When these waves pass through a prism, the different wave lengths are refracted in different degrees. The shortest wave, that produces the sensation of violet, is refracted most, and the longest wave, producing the sensation of red, is refracted the least. The refraction of the other wave lengths is greater than that of the red and less than that of the violet.

Limited range of the eye. Just as the sounds we hear depend on the wave lengths that come to the ear, so the colors we see depend on the wave lengths that reach the eye. There is a great difference, however, in the length of waves perceived by the ear and those perceived by the eye. The human ear perceives musical notes covering a frequency range of 10 octaves, or from about 30 to 30,000 vibrations per second; the eye perceives waves of 395 trillion to about 790 trillion vibrations per second. This range is but a very small part of the total range of light waves. The waves that affect the human eye have been measured, and their approximate lengths are listed in the following table:

Color	Wave Length in Centimeters
Red.....	0.000065 to 0.000077
Orange.....	0.000059 to 0.000065
Yellow.....	0.000055 to 0.000059
Green.....	0.000048 to 0.000055
Blue.....	0.000045 to 0.000048
Indigo.....	0.000041 to 0.000045
Violet.....	0.000036 to 0.000041

Their frequencies are found by use of the law expressed in the formula $N = \frac{V}{L}$. This law applies to sound as well as to light waves. We thus find the frequency of vibration by dividing the velocity of light by the wave length of each of the different colors.

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How a rainbow is formed. We can make a rainbow by means of a spherical glass flask about four or five centimeters in diameter

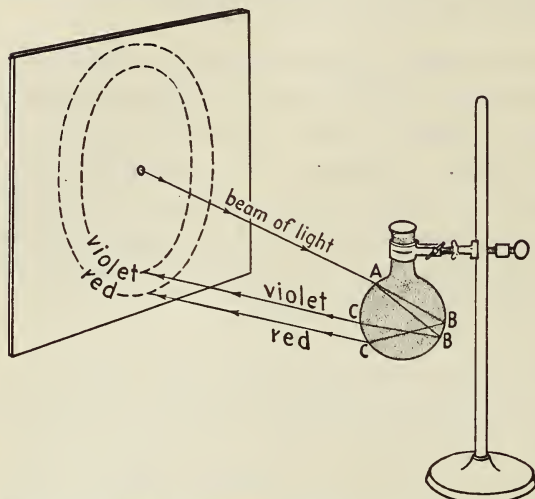


Fig. 356. A beam of sunlight falling upon a flask filled with water and refracted in a complete rainbow.

filled with water. In a darkened room we let a beam of sunlight shine through a hole in a white cardboard screen so as to fall upon the flask, as shown in Figure 356. A small rainbow will form a complete circle on the screen round the opening. The violet edge of the rainbow will be nearest the center of the circle and the red edge on the outside.

The beam of light as it enters the flask at point A is refracted and dispersed, and at points B it is totally reflected. At points C it is again refracted and dispersed as it passes into the air. The violet rays are refracted most and return to the cardboard nearest the center, whereas the red rays are refracted least and return to the outer edge of the rings of color.

To see a rainbow in the heavens, one must be looking at a cloud or mist in which there are drops of water. The sun must be behind the observer and not more than 42° above the horizon. The angle of reflection ranges from 40° for the violet rays to 42° for the red rays of light. The reason the rainbow is semicircular is that only those drops that make the correct angle are seen by the eye. Each drop reflects all seven colors, but from each drop only one color comes to the eye. Each color observed comes from a different drop at a different angle. It is possible sometimes to see a fainter second bow outside of the primary bow. This is made by rays that have been totally reflected twice. In the secondary bow the violet is outside and the red inside.

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The spectroscope. The spectroscope is an instrument that is used for the analysis of light from any source. This instrument is shown in Figure 357.

Light from the source enters the narrow slit S at the focus of the lens in a tube that is called the collimator. The lens changes the diverging rays to parallel rays, and they fall upon the triangular prism P and are refracted and dispersed. After passing through the prism, the

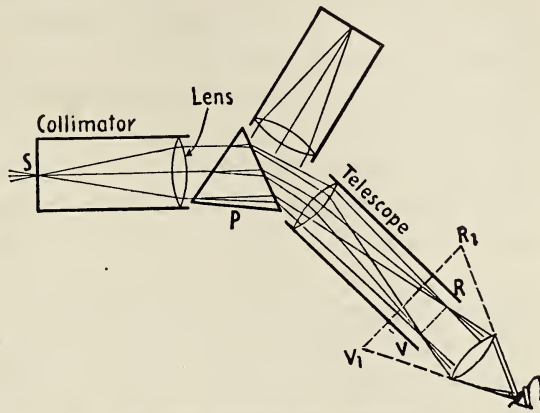


Fig. 357. The above drawing shows the parts of a spectroscope, an instrument used to analyze light waves.

Primary and secondary rainbows can be seen in the mist that rises perpetually in the deep canyon at the foot of the mighty Victoria Falls in the heart of Africa.

Paul Photos



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different colors are brought to focus by the objective in the telescope to form a sharply defined spectrum at its principal focus. A separate image of the slit is formed by each wave length present. The eyepiece magnifies the spectrum from RV to R_1V_1 . The third tube, placed above the second face of the prism, contains an illuminated scale. Light from this scale is reflected at the second face of the prism, enters the lens, and adds an image of the scale to the image of the spectrum. A similar instrument, called the spectrometer, provides for convenient measurement of wave lengths by replacing the third tube with a circular scale.

The spectroscope and scientific knowledge. The spectroscope in the hands of scientists has succeeded in unlocking more secrets of nature than any other single device. The spectroscope tells much about the nature and internal structure of atoms, for example, for all atoms can be made to give off waves of light by heat or electricity. These waves are analyzed with the spectroscope and the character of the atoms is shown. The light emitted by atoms can be studied after they have traveled a billion miles. The spectroscope is so sensitive that it can detect the presence of a pinch of salt dissolved in a bathtub of water, or the presence of any of the seventy elements in a piece of brass the size of a pin-head. At the present time, many astronomers and physicists are busy analyzing the composition of stellar bodies on the basis of spectroscopic photographs of the light waves from these bodies. Thus they are constantly acquiring new knowledge of the nature of the universe around us.

Ultraviolet rays. Some light waves are too short and others are too long to be visible to the eye. Those that are shorter than the violet rays of light are called ultraviolet rays, and those that are longer than the red rays of the spectrum are called infrared rays. The spectrum may be received on a photographic plate and photographed. This photograph will show that there are wave lengths still shorter than the violet that act upon the photographic plate but are invisible to the eye. This ultraviolet region just

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beyond the visible spectrum consists of waves whose length extends from 0.00004 centimeter to 0.0000013 centimeter. Waves in this region, besides affecting a photographic plate, have curative effects in certain diseases. Ultraviolet waves produce sunburn and cause tan and freckles. These short waves are partially absorbed by the earth's atmosphere; consequently the noonday sun, which passes through less atmosphere, causes more severe sunburn than does the sun in the early and late parts of the day. On mountain tops the midday sun may cause very severe burns. A certain amount of exposure to ultraviolet waves is essential, however, for health. Because ordinary window glass absorbs the ultraviolet rays, hospitals and schools are sometimes furnished with windows made of quartz, so that the healthful ultraviolet rays may pass readily through them. Where it is impracticable to use sunlight, artificial lights rich in ultraviolet waves are used.

Infrared rays. At the opposite end of the spectrum are the infrared rays. Their wave length is beyond the range of visibility of the eye, but they can be detected, nevertheless, by special devices. They pass through rock salt more readily than through glass. Therefore they are readily detected with a spectroscope in which rock salt is used in place of glass. They radiate more heat than other light waves and may be detected by a radiometer or by other instruments sensitive to heat waves. With a special film that is sensitive to the infrared rays, pictures can be taken in the dark or under hazy conditions when there is not enough light to take clear pictures with regular film. Aerial photography has been advanced through the use of the infrared film.

Three different kinds of spectra. Sunlight may be separated by a prism into the colors of the solar spectrum. Light from other sources also may be analyzed by use of the prism, but the results are not always the same, because not all sources of light produce all of the colors of the solar spectrum. There are three kinds of spectra: (1) continuous spectra, (2) bright-line spectra, and (3) absorption, or dark-line, spectra.

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Continuous spectra. Continuous spectra are produced by incandescent solids, liquids, and dense gases. If a platinum wire is held in the colorless flame of a burner, the spectrum produced is the continuous band of colors that we see when sunlight is analyzed. The spectrum from an electric lamp, a gas flame, or a candle is likewise continuous, owing to the presence of solids in the source of light.

Bright-line spectra. A bright-line spectrum is produced by an incandescent gas or vapor. If a loop of platinum wire is dipped into a solution of common salt (sodium chloride) and held in a flame, the sodium is vaporized and the color of the flame is yellow. If this yellow flame is examined through the slit of the spectroscope and care is taken that the wire itself is held so that the spectrum due to it is not seen, only a bright yellow line (or two lines, very close together) is visible. This line is the image of the slit and always comes at the same place on the scale. This shows that light coming from the sodium flame is not made up of a number of wave lengths, but of the wave length of the yellow light produced. When a platinum wire is dipped into a solution of lithium chloride and held in the flame, two distinct images of the slit are seen, one in red and one in yellow. When the flame from calcium chloride is examined, two images of the slit appear, one in green and one in red.

All gases and vapors, when rendered incandescent, form bright-line spectra. All of these spectra are characteristic of the respective substances, every known substance having a different spectrum. If the characteristic spectrum of each of the ninety-two elements is known, the presence of any of the elements in the source of light can be determined by use of the spectroscope. Identification of elements by their spectra is called spectrum analysis. The investigation of substances that show lines in their spectra that are different from the lines in the spectrum of any substance already known has brought about the discovery of a number of new elements. The presence of elements in portions too minute for chemical analysis can be detected by means of the spectrum analysis.

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Absorption, or dark-line, spectra. The third type of spectra is one in which dark lines appear at intervals across the color bands of the spectrum. Dark-line spectra are found when the light from an incandescent solid passes through a gas or vapor. We can see a dark-line spectrum by observing through a spectro-scope the spectrum of an electric lamp with some sodium salt vaporized between the lamp and the slit of the collimator. A dark line will be seen in the yellow of the continuous spectrum. This shows that the vapor of sodium absorbs the wave lengths that produce the yellow in the spectrum. The vapors evidently absorb those waves that they produce when they are the sources of light. Therefore the relative position in the spectrum of dark lines produced by any vapor is the same as the position of the bright lines produced by the same vapor when it is incandescent.

One example of the dark lines in the spectrum is the Fraunhofer lines, which were discovered in 1814 by a German scientist named Fraunhofer. These lines indicate the presence in the sun's atmosphere of heated vapors or gases that absorb the same kinds of light that they emit. The Fraunhofer lines, or dark lines, in the solar spectrum furnish the clue to the elements existing in the sun's atmosphere. Some of the most prominent of these lines are designated by the first eight letters of the alphabet, and serve as convenient points of reference in the scientific analysis of a spectrum. The line designated as *A* is near the outer end of the red color in the spectrum, and the line designated as *H* is near the end of the violet color in the spectrum.

The sun is an incandescent solid that produces a continuous spectrum. In its atmosphere are nonluminous vapors of elements found in the sun. Each vapor, while it is luminous, produces bright-line spectra, but when the vapors are not luminous they absorb the wave lengths that they emit while luminous. Consequently the dark lines of the absorption spectra appear in the continuous solar spectrum. By these lines it is shown that the sun contains many of the elements that exist in the earth. In the same way the composition of the faraway stars can be shown by spectrum analysis.

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Calculating the velocity of moving stars. We remember Doppler's principle as applied to sound: *When a sounding body is moving toward the observer the wave length is shortened, and when a sounding body is moving away from the observer the wave length is increased.* In just the same way, when a star is moving toward the earth the wave lengths of its light are shortened, and when it is moving away from the earth they are lengthened. The effect of this is that, in the star's spectrum, the lines are displaced toward the violet end when the star is moving toward the earth and toward the red end when it is moving away from the earth. From this displacement the velocity with which the star is moving either toward the earth or away from it can be calculated.

Waves of different lengths produce the sensation of colors. We have seen that sunlight is white and that it is a combination of waves of different lengths. When light is dispersed into the wave lengths that compose it, each separate wave length produces in our minds a different sensation that we call color. When we were studying sound, we found that there are nerve filaments in the inner ear that respond to the tones of different pitches. The eye, however, does not have separate receivers for each wave length; in fact, there are only three sets of receivers. One set is more sensitive to the red end of the spectrum; another is more sensitive to the middle of the spectrum; the third is more sensitive to the violet end. Each set of receivers, however, is responsive to some extent to the greater part of the spectrum. The character of the sensation of color depends upon the relative response of the three receivers to the light entering the eye.

Color blindness. When a person's eyes are defective in one set of receivers, he is color blind. More persons are color blind to red than to any other color. To a person color blind to red, certain shades of red appear black, and all other shades of red appear as colors different from red. Many people are somewhat color blind and do not know it. Because traffic signals use colored lights, it is necessary to test drivers for color blindness. This is especially

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necessary for locomotive engineers. A rigid test in which the individual is required to match certain colors is usually given.

Chromatic aberration. We have learned that white light is made up of different wave lengths and that the amount of refraction of light waves depends upon their wave lengths. With these two facts in mind, then, we can readily understand why a lens disperses white into color bands just as a prism does. This dispersion of white light by lenses, called chromatic aberration, is shown in Figure 358. Since the violet

waves are the shortest, they are bent most, whereas the longest wave lengths, those of the red, are bent least. The violet rays come to a focus nearer the lens than the red rays. If a white

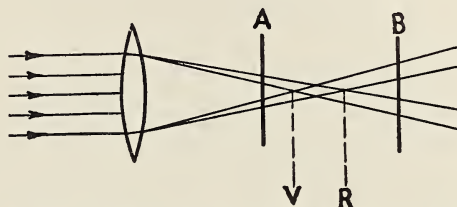


Fig. 358. Diagram showing white light dispersed by a lens. This process is chromatic aberration.

cardboard is placed at A, in Figure 358, a red fringe will appear at the outer edge. If the cardboard is placed at B, a violet fringe is seen. Newton thought that this defect made the use of lenses for optical instruments

impracticable. In later years, however, different kinds of glass were found to have different dispersive powers. This defect of lenses may be remedied by a combination of a convex, or convergent, lens of crown glass with a concave, or divergent, lens of flint glass. The two lenses are usually cemented together with Canada balsam. Figure 359 shows

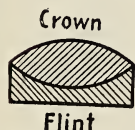


Fig. 359. Achromatic lens in cross section.

an achromatic lens. The light passing through such a lens is brought to a focus without being dispersed.

Synthesis of white light. We have been shown that white light can be dispersed by the use of a prism into the seven colors of the solar spectrum. It is also possible to combine these seven colors to reproduce white light. Sir Isaac Newton did this by using a second prism placed in the position II, shown in the diagram,

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Figure 360. The dispersion of white light into the seven primary colors is called the analysis of white light. The combining of these colors into white light is called the synthesis of white light.

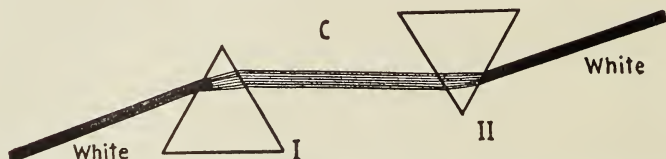


Fig. 360. The above drawing illustrates a method for studying the dark lines that appear in sunlight and for cutting off certain rays.

If a white cardboard is placed at *C* in Figure 360 so that the red rays are cut off, the remaining colors are combined by the second prism to form green light. If red is subtracted from white light, green is left. If red and green are combined, white light results. We can demonstrate this by using the rotating disk shown in Figure 361. This is known as a Newton disk. If the disk is made up of red and green in the proper proportion and rotated rapidly, we do not see the red or green colors, but white. The reason for this is the duration of visual impressions. When the disk is rotating rapidly, the visual impressions of the red and green colors are combined, and the resultant sensation in the brain is of white, caused by the combination of red and green sensations. Any two colors that combine to produce the sensation of white are called complementary colors. If blue and yellow are combined, for example, white is produced; therefore, blue and yellow as well as red and green are complementary colors.

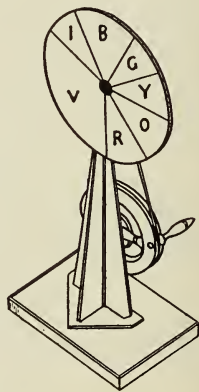


Fig. 361. A Newton disk for the combination of colors.

The seven colors of the spectrum, which are called the elementary colors, cannot be analyzed further. They combine to form white light, as has been shown. White light is also formed by the combination of two complementary colors. But three of the elementary colors can be combined, not only to form white

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light, but, when mixed in the right proportion, to form any color. These three colors are red, green, and violet. They are conventionally called the primary colors.

HOW CAN ANY DESIRED COLOR BE MADE?

Mixing pigments. Our everyday experiences with colors may seem to contradict some of the statements in the preceding paragraphs. It has just been stated, for example, that when we combine the color sensations of blue and yellow we get white. But when we mix yellow and blue paints, or draw on the blackboard a broad band of blue with blue crayons, and over the blue a band of yellow, the mixture of the two will make green. Mixing pigments produces a different effect from that produced by combining colors. When we combine colors we are adding one sensation to another, but when we mix color pigments the effect is produced by subtraction. Mixing blue and yellow pigments produces green because blue pigment absorbs all the colors of white light except blue and green, and the yellow absorbs all colors except yellow and green. The result is a pigment that absorbs all the colors except green. In the same way the color resulting from mixing any number of pigments can be explained. When we mix pigments, each one always subtracts certain colors from white light. The three primary pigments, then, are the complements of the three primary colors; they are peacock blue, crimson, and yellow. When these three are combined, all the colors are subtracted from white light and the result is black.

Three-color printing. Three-color printing is used in the printed reproduction of paintings and scenes in which colors are to be reproduced. The process consists in taking three separate photographs of the object, one through a blue-violet filter, another through a green filter, and the third through a red filter. Half-tone plates are made from these photographs. The colored picture is then made by carefully superimposing impressions from the three half-tone plates on white paper. In printing, the ink used with each block is complementary in color to the filter used in making



Paul Photos

This picture shows an artist reproducing his impressions of the sea on canvas. As he does this, he combines many pigments to create exactly the color effects he desires.

the negative from which the block was made. That is, light-yellow ink is used with the block made from the negative taken through the blue-violet filter; a red ink is used with one from a negative made through the green filter; and greenish-blue ink is used with the block from the negative taken through the red filter.

Color of bodies. Why do some bodies appear red and others blue or green? We see objects either because they are self-luminous, like a candle, or because they are illuminated by light from some external source. The color of any body is due to the wave lengths of the light that it reflects or transmits. If it reflects light with a wave length of about 0.00007 centimeter, it appears red. When we paint a barn red, we are simply putting on the barn a pigment that in sunlight absorbs all the waves except the red waves. A piece of white cardboard, if held in a red light, appears as red; in blue light, as blue; and in green light, as green. This is so

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because white reflects all colors. An opaque body reflects certain wave lengths and absorbs all others. If the wave lengths that it reflects are present in the light, the color that is seen is the color of those wave lengths. But if those wave lengths are not present, the body will appear black.

Transparent bodies get their color from the waves that they transmit. If a piece of glass is held up before the sunlight and the light that comes through it gives us the impression of red, we say the glass is red. The glass absorbs all the waves except the red, which it transmits. The color of any object, then, is not something that resides in the object. Rather, it is made up of sensations produced by light waves coming from the object and falling on the eye, which receives and transmits them to the brain.

Some lights deceive. Some artificial lights are deficient in certain wave lengths. Most artificial lights produce the longer waves and are deficient in the shorter waves of blue and violet. In such a light, blue colors and violet colors appear darker than they do in sunlight. In many situations this serious defect of artificial light is overcome by the use of blue lamps, or "daylight" lamps. The mercury-arc lamp is efficient for use where details must be brought out, as in drawing or printing. It is deficient in red waves, however, and therefore it gives a pale or ghostly appearance to the people who work under it.

The color of the sky. Why is the sky blue? Skylight is sunlight scattered by dust particles or water molecules, or by molecules of air. The sky is blue because the short waves are dispersed by the molecules more than are the long waves. Hence they give us the color impression of the blue sky. The longer yellow waves, however, pass through the atmosphere to give us the yellow color of the sun. At sunrise and sunset the sun's rays travel parallel, or nearly parallel, to the earth's surface; therefore, they travel for a greater distance through the earth's atmosphere than during the rest of the day. Only the longest rays, the red, reach us, and so the sun and the surrounding sky are red or red and orange.

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Colors of films. We have seen the beautiful colors of a soap bubble and the colors given off by a drop of oil spreading over water. These are caused by interference. The color bands that we see in soap films are of varying shades of color, because the light falling on the soap film is not of one wave length but is composed of all the wave lengths of white light. The thickness of the film at any point determines the color at that point. Where the thickness is such as to cause interference of red waves, the reinforcement of other waves occurs, and in the place of the red we see its complementary color. The shifting of the color bands is due to the fact that the thickness of the soap film is constantly changing.



Fig. 362. Rays expand outward creating a circle of light on the screen larger than the opening.

Diffraction. If a beam of light L is caused to pass through a small opening in a screen S_1 and to fall upon a second screen S_2 , the circle of light on the second screen is larger than the opening in the first screen, as shown in Figure 362. This shows that

the rays of light deviate outward slightly in passing through the opening. The slight divergence or bending of the rays is called the diffraction of light.

Thomas Young, an English scientist, performed this experiment by passing the light through two holes instead of one. Figure 363 illustrates the result when the experiment is carried out in

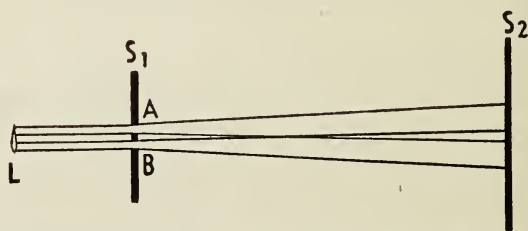


Fig. 363. Two sets of waves passing through holes and overlapping, thus causing interference.

this manner. The light coming from L sets up two sets of waves at A and B . The waves start from those points in the same phase, but as they spread out and overlap they cause interference at

SUMMARY

certain points. Where they are in the same phase, they cause reinforcement. If sunlight is passed through many small openings, the interference of the different light waves produces the various colors of the spectrum.

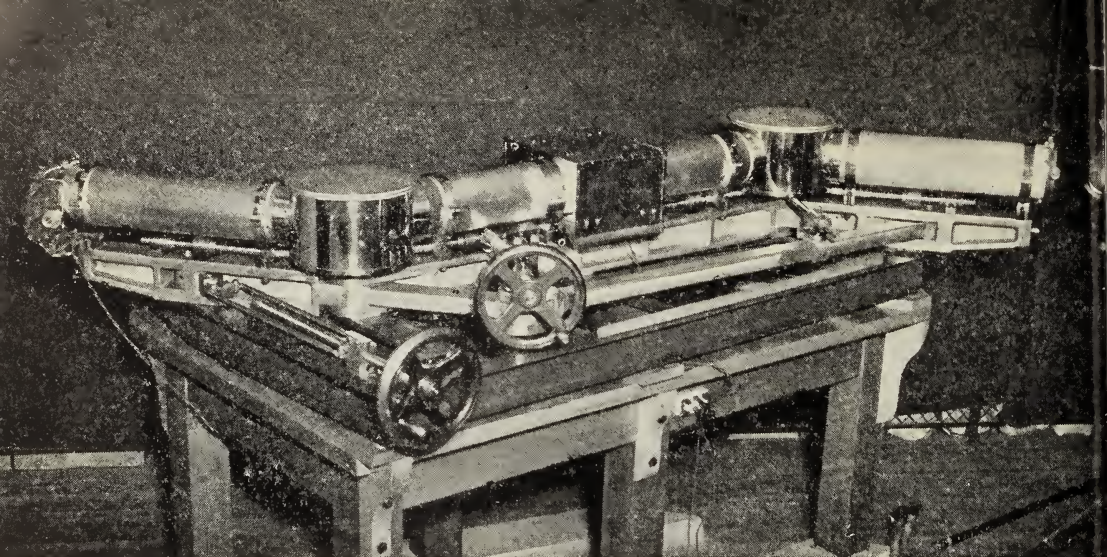
Fraunhofer devised a screen composed of very fine parallel wires spaced at equal intervals. Such a screen, called a diffraction grating, is now made of glass. Very fine lines ruled on this glass with a diamond constitute the grating that causes diffraction and interference. Professor Rowland of Johns Hopkins University made gratings with which he was able to prepare a spectrum of the sun 35 feet long and to measure thousands of Fraunhofer lines as they appeared in the spectrum.

ANSWER THESE QUESTIONS

1. What is the physical difference between white and black?
2. How can white light be analyzed?
3. What causes the appearance of a rainbow?
4. How does the spectroscope enable a scientist to discover the presence of any element in a substance?
5. What are the colors of the spectrum?
6. What do the Fraunhofer lines in the spectrum show about sunlight?
7. How can the invisible ultraviolet and infrared waves be detected?
8. What practical uses are made of these invisible waves?
9. Is the solar spectrum a continuous spectrum, a bright-line spectrum, or a dark-line spectrum?
10. What are the primary colors of the spectrum? What are their complementary colors?
11. What constitutes the color of an object?
12. Why is the sky blue and the sun yellow?
13. How does the diffraction grating cause interference of light waves and produce a spectrum?

SUMMARY

Light energy is produced by disturbances in the motion of electrons in the atoms of luminous objects. Two theories explain light transmission. According to the corpuscular theory, light is



Courtesy General Electric Co.

A spectroscope with tubes having a total length of more than twenty-one feet. This device is used for study of light rays, the visible, the infrared, and the ultraviolet.

transmitted in small particles emitted by a luminous body. The particles move with very great velocity. According to the wave theory, light energy is transmitted in waves of very short length through a hypothetical medium called ether. In this theory the waves are transverse waves that diverge from the luminous point in concentric spheres. The curvature of the waves of light decreases as the distance increases. The direction of motion of the wave front is represented by lines called rays.

The speed of light has been measured by various methods. Michelson measured it by reflecting light over a known distance and measuring the time required. The speed in a vacuum was found to be 299,796 kilometers per second, or 186,284 miles per second. The speed of light is different for each medium through which the light passes.

The intensity of light is measured at the source by a photometer. The unit of intensity is the candle power. The measurement of the intensity of illumination is made by the use of an instrument called the foot-candle meter. The unit of intensity of illumination is the foot-candle. The law for illumination is: *Intensity of illumination received varies as the square of the distance.*

Methods and equipment for artificial lighting are constantly being improved. The efficiency of the incandescent filament lamp has been greatly increased, and many new types of lighting apparatus have emerged, such as the fluorescent lamp.

Light can be absorbed, reflected, or refracted, depending upon the character of the media that it meets. Dark bodies absorb much of the light that falls upon them, though they also reflect some. Smooth polished surfaces, on the other hand, reflect most of the light. The law for reflection is: *The angle of incidence is equal to the angle of reflection.* Mirrors are polished surfaces that form images by reflecting light. Mirrors are either plane, convex, or concave. Plane mirrors form images whose size is the same as the object and whose distance from the mirror is equal to the object distance. The images are behind the mirror and are virtual images. Plane mirrors form images by changing the direction of the wave fronts. Convex mirrors form images behind the mirror (virtual images) that are always smaller than the object. Convex mirrors increase the curvature of the incident waves and make the reflected rays more divergent. Concave mirrors form real images when the object distance is more than the focal length and virtual images when the object distance is less than the focal length of the mirror. Concave mirrors decrease the curvature of the incident waves and make the rays convergent. Incident wave fronts that are straight (with parallel rays) are converged to a point called the focal point of the mirror. The focal distance is one-half the radius of curvature. The formula for convex mirrors is:

$$\frac{1}{\text{Object distance}} + \frac{1}{\text{focal length}} = \frac{1}{\text{image distance}}.$$

The formula for concave mirrors is: $\frac{1}{\text{object distance}} - \frac{1}{\text{focal length}} = + \frac{1}{-\text{image distance}}$, the plus for virtual images and the minus for real images.

Light is refracted when it passes obliquely into a medium of different density. When it enters a medium of greater density, the

EXPLORING THE UNIVERSE OF LIGHT ENERGY

rays are bent toward the normal of the medium. When it enters a medium of lesser density, the rays are bent away from the normal. The index of refraction is the ratio of velocity of light in air to its velocity in other substances.

Lenses are used to refract light and form images. Lenses are made of transparent materials and with curved surfaces. They are either thicker in the center or thinner in the center. When thicker in the center, they subtract curvature from incident waves of light and converge the rays. When thinner, they add to the curvature and diverge the rays. Lenses thicker in the center (convex) converge the waves to a point called the focal point. The formulas for lenses are the same as for mirrors, except that the formula for convex lenses applies to concave mirrors. Convex lenses form real images when the object distance is greater than the focal length, and virtual images when the object distance is less than the focal length. The size of the real or virtual image formed by the convex lens is determined by the ratio of the image distance to the object distance.

The lens in the eye is a crystalline lens. Nearsightedness is due to elongated eyeballs and can be corrected by use of concave lenses. Farsightedness is due to too short eyeballs and can be corrected by the use of convex lenses. The eye is somewhat like a camera. Both the eye and the camera form a real, inverted image, but the eye adjusts the thickness of the lens to focus rays from different distances. This adjustment in a camera is made by the photographer when he moves the lens nearer to the film or farther away from it.

The magnifying glass is a double convex lens. The object distance is very little less than focal length. Its magnification is equal to the ratio of the distance of most distinct vision to the focal length of the lens. A compound microscope has an objective that forms a real image and an eyepiece that forms a magnified virtual image of the real image. Magnification of a microscope is shown by the formula:

$$M = \frac{\text{length of tube}}{\text{focal length of objective}} \times \frac{\text{distance of distinct vision}}{\text{focal length of eyepiece}}.$$

A telescope has an objective of long focal length that forms a real image and an eyepiece that acts as a magnifying glass, magnifying the real image formed by the objective. The magni-

$$\text{fication of a telescope} = \frac{\text{focal length of objective}}{\text{focal length of eyepiece}}.$$

White light is a composite wave made up of different wave lengths. A triangular prism refracts the different wave lengths in different degrees. This process breaks white light into seven spectral colors, and is called the dispersion of white light. A rainbow is formed by the dispersion of sunlight by a drop of water. A spectroscope is an instrument used for the analysis of light from any source. Complementary colors are colors that produce white when combined. Primary colors—red, green, and blue-violet—can be combined to form any color.

Mixed pigments form colors by subtraction. Each pigment subtracts certain colors from white light. The color of any body is due to the light it reflects. Diffraction of light is the deviation of light rays from a straight course. This deviation of the rays is caused by the interference set up when light passes through small openings or around obstacles.

What are some of the invisible waves that are longer than light waves? shorter than light waves?

What are some of the common sources of light?

How can the foot-candles of light on your desk be measured?

Why does a pool of water look to be less deep than it is?

Why is the image seen in a compound microscope inverted?

What two ways can be used to reinvert the image in field glasses and telescopes?

What use can be made of photographs of the finish of races?

Why are sodium-vapor lamps efficient in fogs?

How can the different kinds of rays given off by a piece of white-hot iron be determined?

Why does a red cloth appear to be black in the light of a mercury-vapor lamp?

Why are fluorescent lamps a good source of light in dry-goods stores?

Why are there two different sets of primary colors, one for light and one for pigments?

EXPLORING THE UNIVERSE OF LIGHT ENERGY

SOLVE THESE PROBLEMS

1. If 5 foot-candles are received from a lamp 5 ft. away, what is the candle power of the lamp?
2. If the lamp in problem 1 is rated at 100 watts, how many watts per candle power are used?
3. What is the efficiency in lumens per watt of a 100-watt lamp that gives 125 candle power?
4. A man walks away from a plane mirror at the rate of 6 ft. per second. How fast does he recede from his image?
5. An object is placed 6 cm. in front of a concave mirror with a focal length of 5 centimeters. How far from the mirror is the image? Compare the size of the image and the size of the object.
6. A burning candle is 3 ft. from a double convex lens with a focal length of 9 inches. How far from the lens must a cardboard be placed to get the image? What is the magnification in the image?
7. A magnifying glass has a focal length of 2 inches. What is its magnifying power?
8. A compound microscope is constructed of a lens of 5 cm. focal length for the eyepiece and a lens of 5 cm. length for the objective. If the object is placed 6 cm. from the objective, what is the linear magnification of this arrangement?
9. In a field glass the eyepiece has a focal length of 1 in. and the objective a focal length of 8 inches. What is its magnifying power?

INVESTIGATIONS

1. With a light meter find the foot-candles on a reading table. Examine the light in different rooms.
2. Try different lamps at various distances to see what light on a book is best suited for reading and then measure it with a foot-candle meter.
3. Polished metal mirrors with a convex curvature are used for decorative purposes. Examine one and determine its disadvantages as compared to a plane mirror.
4. Examine the effect of using plane mirrors as side walls in the dining rooms of hotels and restaurants.
5. Construct a telescope by using a lens of long focal length for objective and short focal length for eyepiece. Explain the color bands seen around the image. How is this avoided in good field glasses?



Control room of a large broadcasting station. With the dials on his instrument board, the engineer controls tone volume and eliminates blaring and harshness. The most satisfactory sound-meter reading has been found to be between 20 and 30 decibels.

Exploring the World of Electromagnetic Waves



ELECTRIC WAVES AND ATOMIC RADIATION

On January 8, 1815, a great battle was fought at New Orleans between the armies of two countries that had signed a treaty of peace in Europe sixteen days before the battle. The opposing armies did not know that a treaty of peace had been signed. Such a thing could not happen now. What happens in Europe today you will hear over the radio tonight. It is possible to talk to

THE WORLD OF ELECTROMAGNETIC WAVES

friends in a great ocean liner far out at sea. If a business man in your town wishes to talk to someone in London or Honolulu or Havana, all he has to do is to pick up his telephone and ask "long distance" to get him the party. You can tune in tonight on your short-wave radio and listen to a concert played in South America. All these realities of modern communication are commonplace to the young people in the schools of today, but they would have been incomprehensible miracles to the young people in school fifty years ago.

In recent years, scientists have enabled people to see as well as to hear things far away. These achievements are due to the application of well-known facts and laws of physics. Millions of dollars and years of scientific investigation have been spent in developing television. The sending apparatus changes light coming from a scene of action to millions of high-frequency electric impulses. The receiving apparatus changes these electric impulses to points of light which it combines into a moving image of the scene. Television is not yet in general use, but before the young people of today are many years older a combination radio and television receiver will enable them not only to hear persons many miles away but to see them.

You have heard or read of X-rays and X-ray tubes and of the hundreds of vital uses to which they are put. It will be interesting to learn how X-rays are produced, what their nature is, what they will do, and how the million-volt X-ray tube of today was developed from the small tube that was first evolved.

Until recently the atom was thought to be the basic indivisible particle of matter. Then it was discovered that atoms can be broken up and their structure changed. This discovery aroused great general interest because in the process of disintegration of the atom a vast amount of energy is released that may be controlled and used for the advancement of humanity.

In this unit you will learn how sound waves are changed to electromagnetic waves that will travel in all directions over the world. You will learn how these electromagnetic waves are taken out of the air and changed back into sound waves; how it has

NATURE OF ELECTROMAGNETIC WAVES

been made possible to see what is happening far away; how electrons shooting across a vacuum and striking a target produce penetrating X-rays. And you will learn how atoms are being smashed and what has been the result so far.

AREAS OF STUDY

1. *What is the nature of electromagnetic waves?*
2. *How are sound and electric waves changed into radio waves?*
3. *How are radio waves changed into spoken words?*
4. *How has television been made possible?*
5. *How can we see through opaque objects?*
6. *What have scientists learned from the breaking up of an atom?*

AREA ONE

What Is the Nature of Electromagnetic Waves?

In our study of light we learned that light energy originates in the oscillation of electrons, and is carried by waves in the ether at the speed of 186,000 miles per second. This energy produces the sensation of light when it is transmitted to the eye. But the eye, like the ear, has a limited range of perception. Only those light waves whose wave lengths are between 0.000036 centimeter and 0.000077 centimeter cause the sensation of light. This is a very small fraction of the total range of wave lengths.

The electromagnetic spectrum. We also learned that the vibration of electrons sends out both longer and shorter waves than those

of light. But while nature has provided us with a means of detecting the waves we call light waves, it has not provided means for detecting waves that are longer or waves that are shorter than light waves. It has been necessary to invent devices for the detection of such waves. Waves shorter than the visible spectrum, from 0.00000012 to 0.000036 centimeter, are ultra-violet waves. Such waves are detected by photography and fluorescence. Still shorter wave lengths, from 12×10^{-8} to 11×10^{-8} , are known as X-ray waves. These may be detected by photography and ionization. Waves of still shorter lengths are the gamma rays, and the shortest of all are the cosmic rays. Waves longer than the visible spectrum are the infrared, starting with waves more than 0.000077 centimeter long and extending to waves 0.03 centimeter long. These are detected by the thermocouple and the radiometer. They are the radiant heat waves. Longer waves than these are the Hertzian electric waves with lengths varying between 1 meter and 30,000 meters.

These long electric waves are known to us as "radio waves." They are used in radio communication. The discussion on the following pages explains how radio waves are produced and how they are received.

A forerunner of radio. In 1842, Joseph Henry discharged a Leyden jar through a coil of wire in the center of which was a needle, as shown in Figure 364, thus magnetizing the needle. He found, however, in repeating the experiment, that the polarity of the needle was not always the same, although the coatings of the jar were always charged in the same way. That is, if a positive charge was put on the outside coating and the experiment was always performed in the same way, the point of the needle would sometimes be north and sometimes south. The only explanation for this was that the discharge was oscillating and that the magnetism

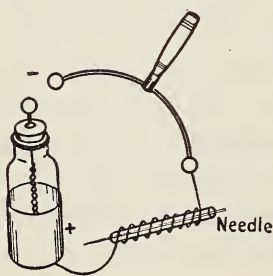


Fig. 364. Apparatus for Henry's discovery of oscillation in an electrical charge.

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of the needle was reversed with each change in the direction of the oscillation, the final direction of the needle depending on the direction of the final oscillation. A few years later, an English physicist, Lord Kelvin, proved mathematically that the discharge was oscillatory, and in 1859 the time of one oscillation was determined by photographing the spark.

High-speed oscillations. The rate at which the oscillations occur in the discharge of a condenser is very high. The number of cycles per second depends upon the capacitance of the condenser and the inductance of the circuit, and is often as high as 1,000,000 per second. At this rate the period, or the time for a single cycle, would be one-millionth of a second.

Figure 365A is the conventional diagram of an oscillating circuit and Figure 365B is a graph of the oscillation. The decreasing amplitude of the oscillation is caused by loss of energy. This is called a *damped* oscillating discharge. An oscillating discharge sets up an oscillating magnetic field and also sets up an oscillating electrostatic field.

The Scotsman James Clerk-Maxwell, one of the world's greatest physicists and mathematicians, pointed out in 1865 that an oscillating discharge should set up waves that would travel with the speed of light. He suggested further that light waves were probably electric waves. In 1888, Heinrich Hertz, a famous German physicist, proved that electric oscillations produce electric waves. He showed that these waves are reflected and refracted like light waves. He measured their wave length and their velocity and proved that they had the same velocity as light waves and differed from light only in wave length. Hertz died at an early age, before he could complete his work, but his epoch-making discoveries aroused great interest among scientists. Investigation of the waves he had discovered, called

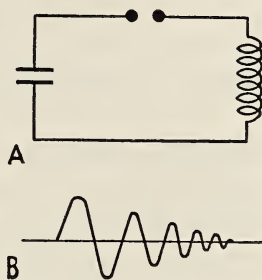
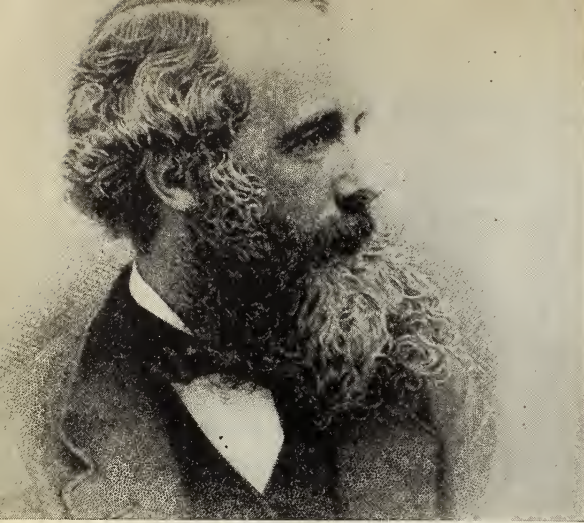


Fig. 365. Diagrams of an oscillating electrical circuit and an oscillating electric current.



James Clerk-Maxwell

(1831-1879)

Clerk-Maxwell was a Scotch philosopher and scientist, educated in Edinburgh and Cambridge. He filled several professorships in philosophy and physics and in 1874 became director of the famous Cavendish Laboratory. He made outstanding contributions to our knowledge of electrical phenomena. His book *Electricity and Magnetism* is a permanent classic in the literature of physics.

The Bettmann Archive

Hertzian waves, was carried on, until today scientists have succeeded in creating the wonders of radio communication.

What we mean by resonance between electric waves. In the study of sound, an experiment was performed in which the sound waves sent out by a vibrating fork set another tuning fork into vibration, provided the latter had the same natural period as the former. The vibration of the second fork was called sympathetic vibration, and was given as an example of resonance.

Sir Oliver Lodge, English scientist, performed an experiment which showed that electrical circuits can also be tuned to respond sympathetically. His apparatus consisted of two Leyden jars of the same capacitance. As shown in Figure 366, the inner and outer coats of the jars are connected by loops. The loop used with jar A is of fixed length with a spark gap at nn_1 . The

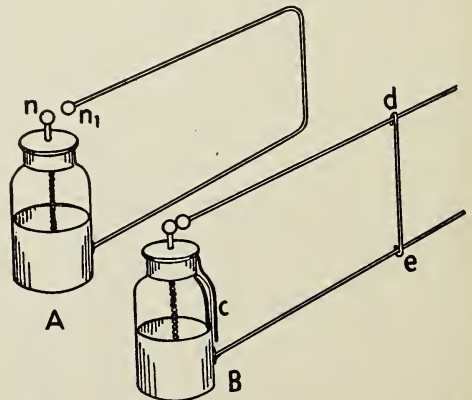


Fig. 366. The apparatus with which Sir Oliver Lodge demonstrated the resonance of electric waves.

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length of the loop of jar *B* may be changed by moving the cross-piece *de*. At *c* is a strip of tin foil separated from the outer coat by a short gap 1 to 2 mm. wide. The other end of the tin foil touches the inner coat of the jar. At each discharge of the jar *A* across the gap *nn*₁, a spark will occur at *c* if the crosspiece *de* is placed at a certain distance from the jar. If *de* is moved away from that position the spark at *c* does not occur.

Tuned circuits. This experiment shows that two electrical circuits can be tuned to respond to each other sympathetically. It shows also that, just as two tuning forks that are in resonance do not respond when the frequency of one is slightly changed, so electrical resonance disappears when the natural periods of the two circuits are not the same.

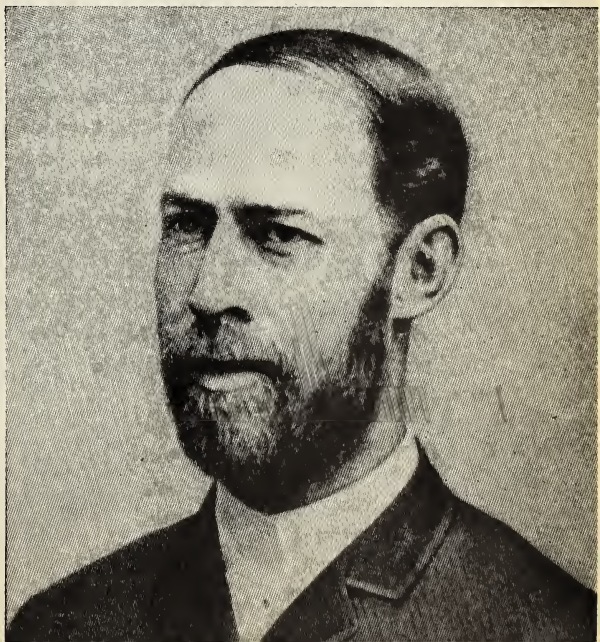
How may two electrical circuits be tuned to put them in resonance? Or, how may the number of oscillations per second in a circuit be altered? Before answering these questions, let us recall the meaning of the terms period, frequency, wave length, and velocity, definitions we learned in the study of sound and light waves in Units Six and Eleven.

The relation of velocity, wave length, and frequency, as we learned, is: velocity = wave length multiplied by frequency, or

Heinrich Hertz (1857-1894)

Heinrich Hertz was born and educated in Germany. He received his higher education at the University of Berlin and later held professorships in physics in many German universities. His experiments in electricity led to his discovery that electricity travels in waves with the speed of light. The electromagnetic waves with which he experimented are now called Hertzian waves.

Century Photos, Inc.



THE WORLD OF ELECTROMAGNETIC WAVES

$V = L \times N$. Since the velocity of electric waves is 300,000,000 meters per second, $300,000,000 = L \times N$, from which we have

$$L = \frac{300,000,000}{N}, \text{ or}$$

$$N = \frac{300,000,000}{L}.$$

If the frequency of oscillation is, for example, 1,500,000 per second, the wave length can be found by the formula

$$L = \frac{300,000,000}{1,500,000} = 200 \text{ meters.}$$

Determining the "pitch" of electric waves. Now let us answer this question: How may the number of oscillations and the wave length in a given electrical circuit be varied? Figure 367 is

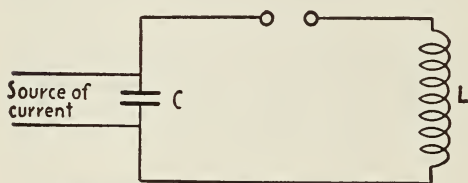


Fig. 367. Diagram of an electrical circuit.

a diagrammatic representation of the electrical circuit under investigation. It may be shown mathematically that, with T as the period in seconds, L the inductance in henries, and C the capacitance in farads, $T =$

$2\pi\sqrt{LC}$. This means that if we increase the inductance or the capacitance or both, the period of the oscillation is increased, and since frequency is the reciprocal of the period, the frequency is decreased. But if we decrease the inductance or the capacitance, the frequency of the oscillation is increased and consequently the wave length is decreased.

How can capacitance and inductance be varied? If the student will refer to Unit Eight, he will see that the capacitance of a condenser can be varied by changing the effective area of the plates. In a variable condenser this is done by turning one set of plates in or out of the other set.

Inductance may be varied by changing the number of turns in the coil of a circuit. In Lodge's experiment, Figure 366, the frequency in the two circuits could be made the same only by

SOUND WAVES CHANGED INTO RADIO WAVES

adjusting the length of the variable loop, since the capacitance of the condensers was the same. How inductance and capacitance are used in the tuning of electrical circuits is shown in further discussion of the radio circuit.

ANSWER THESE QUESTIONS

1. What is the range of wave lengths that we can see? How does it compare with the range of wave lengths that we can hear?
2. How are waves detected that are shorter than the visible limit? longer than the visible limit?
3. What wave lengths are properly called Hertzian waves?
4. How did Henry discover that the discharge of a condenser is oscillating?
5. How did Hertz prove that an oscillating discharge across a spark gap sets up waves in the ether?
6. What are the essential elements of an oscillating circuit?
7. How did Lodge demonstrate resonance in electrical circuits?

AREA TWO

How Are Sound and Electric Waves Changed into Radio Waves?

Investigation of the longer wave lengths by Hertz, Lodge, Branly, and others was directed toward a better understanding of electric waves rather than toward an attempt to develop a signaling device. Branly, however, made the discovery in 1889 that a mass of metal filings placed in a glass tube becomes more compact under the influence of electric vibrations. This was an important step toward the development of radio signaling.

The first radio receiver. Guglielmo Marconi made the first successful effort to send signals over appreciable distances. Using Branly's discovery, Marconi devised the coherer, a glass tube loosely packed with metal filings held in by two metal plugs. When a coherer is placed in a battery circuit, the loosely packed filings offer so much resistance that scarcely any current flows

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through it. But Hertzian waves cause them to stick together, or cohere, and thus reduce the resistance enough so that current flows and operates a relay. The relay closes the circuit and a

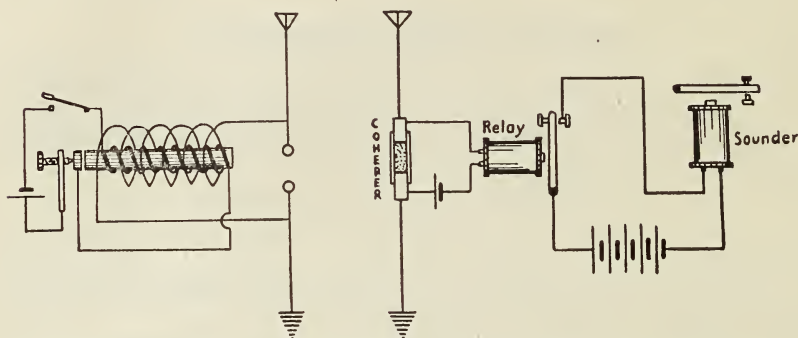


Fig. 368. Diagram of Marconi's signaling device, showing coherer, relay, and sounder.

signal is produced by the sounder. Marconi developed this apparatus, as shown in Figure 368, until, in 1901, he was able to send radio signals from England to St. Johns, Newfoundland.

A diagram of an early form of a sending and receiving set used in wireless telegraphy is shown in Figure 369. The student will note that, in the sending circuit, the AC current is connected through a key to the primary P of a step-up transformer Tr . When the alternating current induced in S flows in a given direction, the electrons flow into one side of the condenser C , for example the upper plate in the figure, making that plate negative. At the same time electrons flow out of

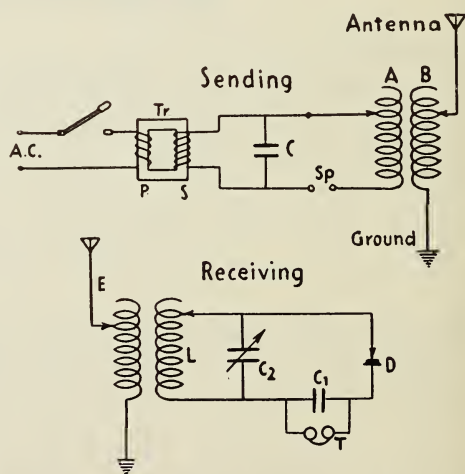


Fig. 369. Diagram of a sending and receiving set as devised by Marconi for his original experiment.

Guglielmo Marconi
(1874-1937)

Marconi was born near Bologna, Italy, and was educated in Italy and England. He showed an interest in electricity at an early age and spent most of his life developing wireless telegraphic equipment and adapting it for practical purposes. His work on the beam-transmission of radio impulses along a directed path is now the basis for long-distance radio communication systems all over the world.

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the other plate, making it positive. When the potential difference between the plates becomes large enough, the condenser discharges through coil *A* and spark gap *Sp*. Since the discharge of the condenser is oscillating and of very high frequency, the current through *A* is an alternating current of very high frequency. When the current reverses, the lower plate of the condenser becomes negative and the top plate becomes positive, and again the discharge across the spark gap sends through coil *A* a high-frequency alternating current. When this high-frequency current flows through *A* it induces in *B* a current of the same frequency that flows up and down the aerial sending out the high-frequency waves. But since the high-frequency current in coil *A* occurs only during the oscillating discharge across the spark gap, it is not a continuous current, but a damped oscillating discharge, as shown in Figure 365, page 745. This means that, though the rate of oscillation is very high, about 1,000,000 per second, the oscillations die out very quickly, each oscillation being of smaller amplitude than the one preceding it. The current passing through coil *A* thus consists of a series of these damped oscillations. The current induced in *B* then sends out a series of damped wave trains.

One of these damped wave trains occurs for each oscillating discharge across the spark gap. Let us suppose there are 1000

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discharges per second. Then there will be 1000 of these damped wave trains per second, as long as the key is closed. Dots and dashes as signals are produced by varying the length of time the key is kept closed.

When these wave trains reach the aerial of the receiving set, shown in the diagram, Figure 369, they cause electrons to oscillate up and down in E at the same high frequency. This flow causes an alternating current of the same frequency to be induced in L , and we have a high-frequency current flowing in the closed circuit. Before the incoming waves will set up this current, the closed circuit must be tuned so as to be in resonance with the open circuit. This may be done by changing the capacitance and inductance of the closed circuit. The capacitance is altered by means of a variable condenser C_2 . The inductance is changed by varying the number of turns in L .

A high-frequency alternating current does not cause the diaphragm of a telephone receiver T to vibrate, as it does not respond to vibrations above 10,000 per second. Even if the diaphragm were to vibrate, the ear could not hear the sound waves above 20,000 vibrations per second.

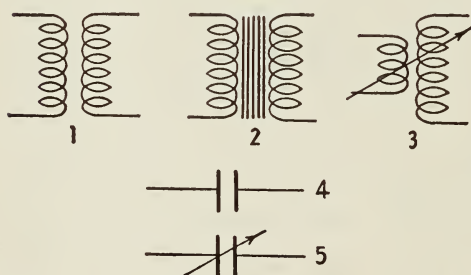


Fig. 370. Symbols used in diagrammatic representations of the parts of a radio circuit.

In order to understand radio drawings, we need to become familiar with certain symbols. Figure 370 shows the symbols used in radio circuits for (1) a transformer with an air

core; (2) a transformer with an iron core; (3) a variable air-core transformer; (4) a fixed condenser; and (5) a variable condenser.

Rectifying radio waves. The sending set sends out discontinuous waves or waves made up of trains of damped waves. That is, one wave train dies out before the next begins. These discontinuous waves induce a discontinuous current in the closed circuit

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of the receiving set. If this oscillating current can be changed to a direct current, each wave train produces the effect of a single pulse in one direction. To

do this, a crystal rectifier is used, as represented by *D* in Figure 369. Certain crystals such as galena, silicon, and carborundum have the property of conducting currents in one direction only.

Figure 371 illustrates the effect produced by the crystal detector on a damped wave train. Figure 371A shows a damped alternating current. Figure 371B shows this current rectified. Figure 371C shows that the train of rectified high-frequency impulses of *B* have the effect of a single pulse for each train. The pulses in *B* follow each other so rapidly that they act as a continuous impulse, as shown in *C*, until that wave train dies out. As there are about 1000 wave trains per second, they cause audible vibrations in the telephone. The wave-train frequency is known as *audio frequency*, while the much higher frequency of the impulses within each wave train is called *radio frequency*.

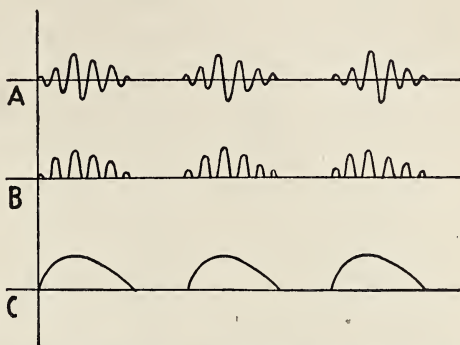


Fig. 371. Diagrams showing the effect of a crystal detector on the behavior of a damped wave train.

The vacuum tube. The vacuum tube is used as a rectifier of the alternating current in the receiving set. The first form of vacuum tube, or Fleming's valve, as it is usually called, is a vacuum tube containing two electrodes: a filament, like the filament of the incandescent lamp, and a plate of copper or other suitable metal. The first scientist to discover that a current would flow from a hot filament to a plate in a bulb was Thomas A. Edison. He discovered this while experimenting with a two-electrode incandescent bulb, but he could not explain the mysterious effect. The electron theory, however, makes it clear that the hot filament throws off electrons and the positively charged metal plate

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attracts them. About twenty years later Fleming used a two-electrode tube for changing alternating current in the filament circuit into direct current in the plate circuit.

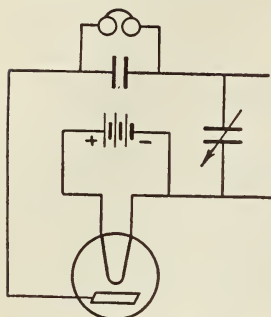


Fig. 372. A two-electrode tube in the receiving circuit.

How this two-electrode tube can be substituted for the crystal detector in the receiving circuit is shown in Figure 372. When the alternation of the incoming current makes the plate positive, electrons from the hot filament are attracted to the plate and flow toward the plate. But when the incoming current reverses, making the plate negative, electrons are repelled by the plate, and no current flows.

The three-electrode vacuum tube. Lee De Forest, an American scientist, added a third electrode, the grid, to the two-electrode tube, thus inventing the audion tube and making possible the modern miracle of radio. In the audion tube is a filament surrounded by a plate, and between them the third electrode, called the grid. This is usually in the form of a fine wire that is wound close to, but not touching, the filament.

When the tube is operating, the filament is connected to a storage battery of 6 volts called the “A” battery, as shown in Figure 373. The current heats the filament, which then gives off electrons. The plate in the tube is connected to the positive side of a battery which has from 20 to 100 volts. This battery is called the “B” battery and its effect is to charge the plate positively. The electrons that are given off by the filament are attracted by the positively charged plate, and pass to it through the meshes of the grid.

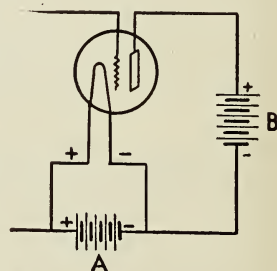


Fig. 373. An audion tube connected in the receiving circuit.

The action of the grid. The student will see that if the grid has no charge a steady current of electrons flows through the tube

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from the filament to the plate. The purpose of the grid is to control this flow of electrons from filament to plate. If the grid is charged positively, it helps to attract electrons from the filament, and, as most of the electrons slip through the grid to the plate, the current is increased. When the grid has a negative charge, it resists the flow of electrons and the current is decreased. If the negative potential of the grid is strong enough, the current is reduced to zero.

The three-electrode vacuum tube has four functions in radio as (1) a detector, (2) an amplifier, (3) an oscillator, and (4) a modulator. In all these functions the tube produces variations in the steady plate current by means of variations of the potential difference between the grid and the filament. The filament voltage for radio tubes is generally a fixed voltage prescribed by the manufacturer, so that it is the variation in the grid potential that produces the variation in plate current. The relation of the variation in grid potential to the variation in plate current is of much importance for an understanding of how the audion tube acts as a detector tube.

How the audion tube acts as a detector. For the sake of simplifying the explanation, let us suppose the incoming waves are of the discontinuous type sent out by the station described on page 750. This, the student will remember, sent out the damped wave trains set up by a condenser and spark gap. Such discontinuous waves cannot be used for wireless telephony. The audion tube must change the alternating current (oscillations) to a direct pulsating current before it will cause the diaphragm of the telephone receiver to make audible vibrations.

Operators make the vacuum tube act as a detector (1) by using a grid condenser and a grid leak, or grid resistor, connected in the grid circuit, or (2) by applying a negative voltage from a "C" battery or some other source to give the grid a strong negative charge so that the tube acts at the lower level of its characteristic curve. The first action is known as grid leak or condenser detection and the second as grid bias detection.

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Effect of grid condenser. Let us see how the vacuum tube works with a grid condenser in the grid circuit, as shown in Figure 374. Let us suppose that signals are coming in and an oscillating current is flowing in coil L_1 . This, by magnetic induction,

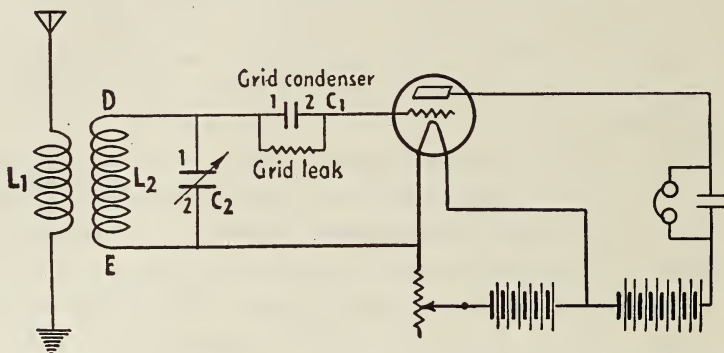
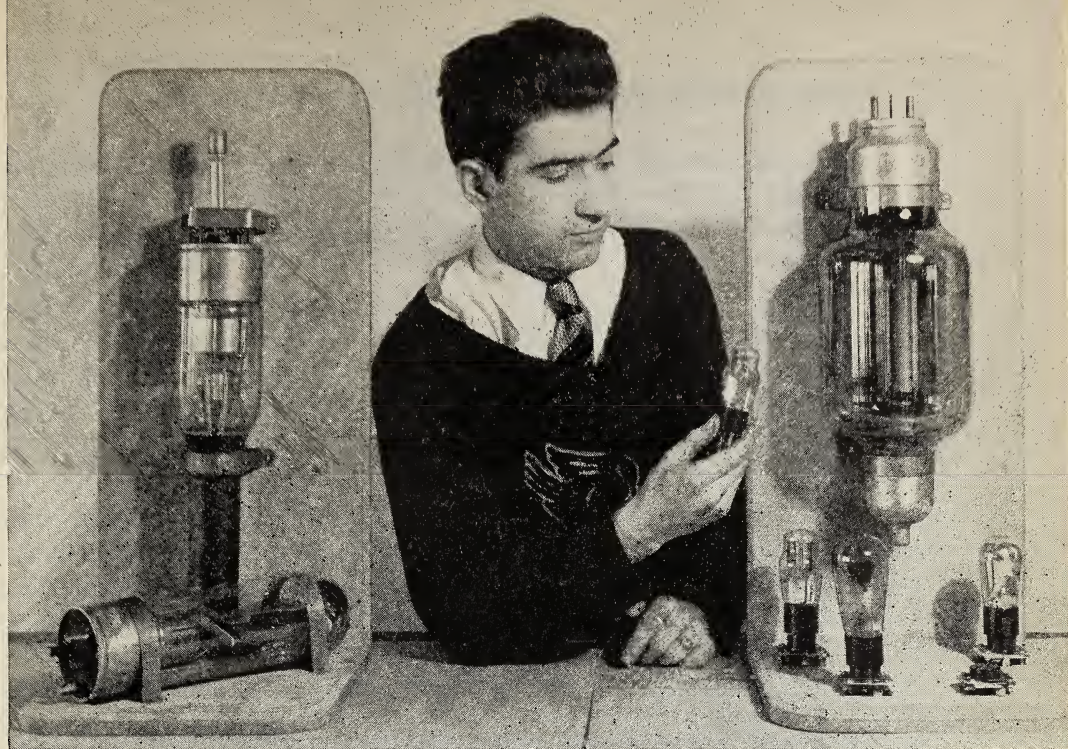


Fig. 374. Diagram of a receiving circuit with a condenser in the grid circuit.

induces an oscillating current in L_2 if the grid circuit is properly tuned. During one-half of a single cycle the electrons flow out of plate 1 of grid condenser C_1 and plate 1 of condenser C_2 , through the coil from D to E , and into the filament and plate 2 of C_2 . Plate 1 of the grid condenser is positive because it has lost electrons. Electrons are attracted from the filament into plate 2 of the grid condenser. In the next half of the cycle, electrons flow into plate 1 of each condenser, but those in plate 2 of the grid condenser cannot get out, because electrons going from the filament to the grid repel them. The same process is repeated in the next cycle and there is left a slightly greater excess of electrons on plate 2. As the number of electrons on plate 2 increases, the grid becomes more and more negative until it repels the passage of electrons from the filament.

Grid leak. The tube will be blocked by the charge on the grid and there will be no further action in the tube unless some way is provided for the excess of electrons to escape from the grid. This escape is provided by a grid leak, or grid resistor, connected as shown in Figure 374. The resistance must be high,



Vacuum tubes are made in a wide range of size. The small tubes are used in the smaller receiving sets while the large tubes are used in radio-broadcasting stations.

generally about one million ohms, in order to allow the electrons to leak off at a slow rate. The excess of electrons should leak off before the next signal impulse comes in.

Grid voltage and plate current. As has been shown, while one signal impulse is coming in, the grid is growing more and more negative. The more negative the grid becomes the more it reduces the plate current. Throughout each wave train, i.e., series of cycles, the average plate current grows less and less. So we get a fluctuating direct current, which changes once for each wave train. For 1000 wave trains per second the diaphragm of the telephone vibrates 1000 times per second, and the receiver gives forth an audible vibration.

To understand clearly the principle of grid bias detection, we must plot the characteristic curve diagrammatically in order to show the relationship between the grid potential variation and

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the plate current variation, as shown in Figure 375. In this curve, two bends occur, one at the bottom and one at the top. The one at the bottom, E , occurs at some negative-grid potential value,

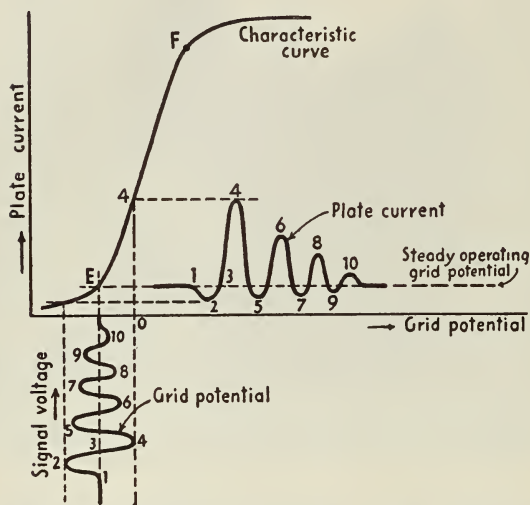


Fig. 375. Characteristic curve showing relation of the grid potential variation to the plate current variation.

the one at the top, F , at some positive-grid potential value. If the proper value of negative grid bias voltage is applied from the "C" battery, the audion tube may be made to operate at the lower bend of the curve. This is what is done in grid bias detection.

Suppose no radio-signal voltage is coming in and only the negative grid potential is present, giving a steady grid voltage,

which is the operating voltage E in the figure. Such a condition causes a steady plate current to form in the plate circuit. This is represented by the height of point E above the zero plate-circuit line in the figure.

When a radio-signal voltage comes in and is applied to the grid, it is superimposed upon the steady operating potential, making the grid potential alternately more and less than the operating potential. This is represented in the figure by the curve vertically below E , showing the signal voltage that is applied to the operating voltage, and drawn about the operating voltage as an axis.

Examination of the voltage curve shows that it oscillates from negative to positive with decreasing amplitude. If vertical lines are drawn from the turning points of the signal voltage to the characteristic curve, the points of intersection determine the plate-current curve. When plotted as the plate current, it will be

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noticed that these points of intersection approach a straight line in the vicinity of the lower part of the characteristic curve where the bend is sharp. This indicates that the rectification is more complete in this region. The curve in Figure 376 represents the effect of this rectification on the plate current as applied to the diaphragm. Grid bias detection is regularly used in the radios of all modern airplanes.



Fig. 376. Diagram showing the effect of rectification on the flow of the plate current.

How the vacuum tube acts as an amplifier. The vacuum tube used as a detector always amplifies the received signal, since the plate current is stronger than the grid current. In other words, the tube develops more power in the plate circuit than in the grid circuit. The tube does not create power but takes the power of the plate circuit from the battery. The grid oscillation merely controls this power, as has been explained.

Tubes in series. The power in the plate circuit may be still further amplified by the use of another tube called the amplifying tube.

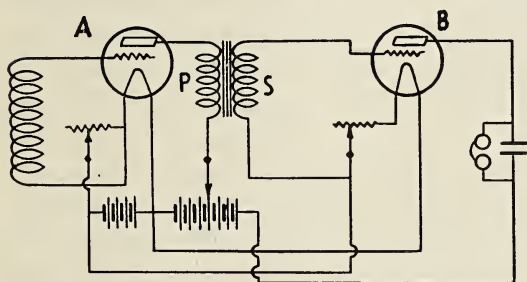


Fig. 377. Diagram showing the arrangement of parts of a receiving circuit with an amplifying tube in series.

This is done, as shown in Figure 377, by passing the plate current of the first tube A through the primary of a transformer and connecting the secondary of the transformer to the grid of the second tube B. The changing of the plate current in the primary by magnetic induction sets up an alternating e.m.f. in the secondary of the transformer. This sets up a corresponding alternating e.m.f. in the grid of the second tube, the e.m.f. having the same frequency as that in the plate circuit of the first tube. The second tube amplifies the alternating

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e.m.f. in the manner already explained. The amplifying tube then gives out oscillations of the same form as the oscillations which it has received, but of much greater amplitude. By the use of more amplifying tubes in the setup, the amount of amplification may be still further increased.

How does the audion tube amplify through its regenerative effect?

Next we shall consider another process by which the audion or detector tube may be made to amplify. The process is called regenerative amplification. Since the power in the plate circuit is stronger than that in the grid circuit, a portion of the power from the plate current may be transferred to the grid circuit.

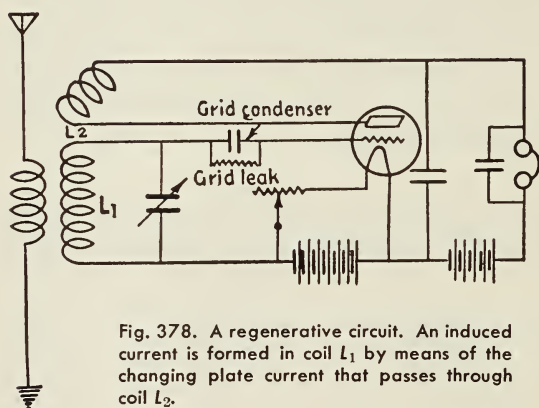


Fig. 378. A regenerative circuit. An induced current is formed in coil L_1 by means of the changing plate current that passes through coil L_2 .

The transfer is accomplished, as shown in Figure 378, by means of a tickler coil L_2 so placed that the changing plate current induces in coil L_1 of the grid circuit an oscillating current of the same frequency. Also, if the coils are properly adjusted, the induced current is of the same

phase as that received by the grid circuit from the incoming signals. This builds up the energy in the grid circuit and causes it to influence the plate circuit more strongly. The result is the same as if an increased signal strength were acting on the grid. These increased potential changes are amplified by the detector tube, producing still greater changes in the current in the plate circuit, and these again react on the coil L_1 and increase the grid oscillation. Thus the plate circuit builds up until it reaches a limit determined by the characteristics of the detector tube.

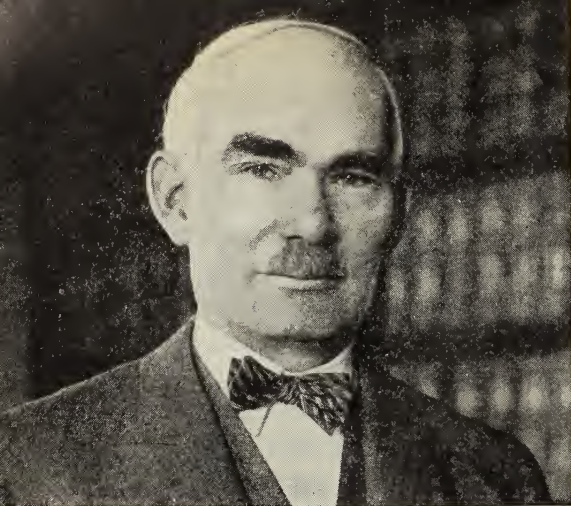
The regenerative effect of the tube described in the preceding paragraph can be carried out to a greater extent than is generally

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desirable for a detector tube. In a nonregenerative vacuum tube the strength of the current in the tuned circuit set up by the incoming signal is determined by the strength of the signal and the resistance of the circuit. In a regenerative circuit the power fed back into the grid circuit by the plate circuit has the same effect in increasing the current as decreasing the resistance would have. By increasing the coupling effect between the tickler coil and the secondary coil, the same effect may be produced as if the resistance of the circuit were reduced to zero. In this case, after the surge of the plate current is started by the current in the tuned circuit, the tube continues to give out oscillations, acting as a generator of a high frequency to which the circuit is tuned. Frequency can be adjusted to any value by changing the inductance or the capacitance of the tuned circuit. The capacity of the tube to send out a high-frequency alternating current whose frequency can be adjusted, is used, as we shall see, in producing the high-frequency continuous current of radio telephony.

Putting the program on the air. Let us now return to the broadcasting of radio waves. We have already considered the broadcasting of discontinuous or damped waves sent out by a condenser and a spark gap in the sending circuit. Damped waves carry telegraphic signals, as we have seen, but will not serve for telephonic communication. Radiotelephony requires high-frequency, undamped oscillations to produce high-frequency waves to act as "carrier" waves. Carrier waves are produced by the regenerative action of the tube described in the preceding paragraphs. These high-frequency waves of uniform intensity would not make a telephone receiver respond. To do this their intensity must be modulated by voice or other sound waves.

Modulation. The manner in which the high-frequency carrier wave is modulated by waves of audible frequencies is essentially as follows: the music or speech to be broadcast is received by a microphone, which acts very much like a telephone transmitter. The audible frequencies picked up by the microphone are then



Lee De Forest

(1873-)

Dr. De Forest is an American inventor, born in Iowa. He graduated from the scientific school at Yale University, and became one of the pioneers in the development of wireless telegraphy in America. His significant contributions are the audion detector and amplifier tubes, which make possible trans-continental telephone service, and other adaptations of three- and four-electrode tubes.

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amplified by a radio tube and impressed upon the grid of the tube in the radio-frequency oscillator circuit. The relatively slow audio frequencies produce corresponding changes in the intensity of the carrier wave sent into the antenna of the broadcasting set by the oscillator. The resultant of the carrier wave and the audio wave is called the modulated wave. In Figure 379, *A* shows the carrier wave generated by the oscillator, *B* the voice (audio) wave, and *C* the resultant modulated wave.

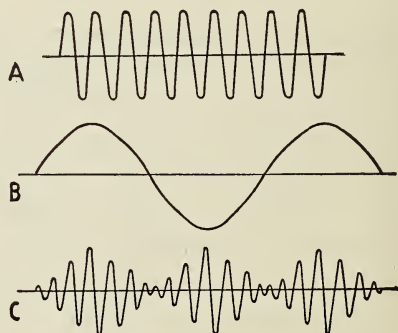


Fig. 379. The modulated wave *C* is the resultant of carrier wave *A* and voice wave *B*.

The aircraft telephone transmitter.

The modern aircraft transmitter has the oscillator and the amplifier together with the modulator. In a complete aircraft telephone transmitter circuit a quartz crystal is used in the grid circuit for frequency control instead of the coil and condenser that are generally used for tuning. In the use of the radio in airplanes, it is difficult to prevent temperature changes and other factors from changing the values of the coils and condensers. In aircraft communication the slightest change in values in the grid circuit

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of the oscillator would endanger the accuracy of the frequency. It has been found that quartz crystals will expand and contract when electrical charges are applied to their surfaces. The rate at which they expand and contract depends upon the way they are cut and upon their thickness. Properly cut, they will maintain a constant frequency. The crystals change their thickness at the rate of the oscillations. The production of modulated waves by the influence of microphone waves upon radio-frequency waves has already been explained.

Frequency modulation. The method of modulating high-frequency carrier waves just described is known as amplitude modulation or A.M., and is the system most generally used. In 1939, however, Major Edwin H. Armstrong discovered a system called *frequency modulation* or F.M. Before he discovered F.M., Major Armstrong made important contributions, including the regenerative feed-back circuit and the superheterodyne circuit. F.M. is considered one of the greatest broadcasting advances since the invention of the vacuum tube. It differs from A.M. in that it changes the frequency according to the voices and music to be transmitted without changing the amplitude, rather than changing the amplitude without changing the frequency. This requires a much wider carrier wave. A frequency-modulating station requires a channel about twenty times wider than the regular 10-kilocycle broadcasting band assigned to A.M. stations. To make room for this channel, F.M. broadcasting uses ultra-short waves.

The advantages of F.M. broadcasting are that the reception is always smooth, since it is not susceptible to static interference, and it will work on much less power than A.M. broadcasting. However, A.M. broadcasting will not be displaced for some time, since most receiving sets are made for A.M. broadcasting.

ANSWER THESE QUESTIONS

1. Why is the Fleming valve better than the crystal as a detector?
2. Why is it necessary to have the plate of a radio tube positively charged?

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3. What kind of charge on the grid is necessary to increase the plate current?
4. How is it possible for a small change in the power input in the grid circuit to cause a large change in the power output of the plate circuit?
5. What is the essential difference between a regenerative circuit and one which is nonregenerative?
6. How is the frequency of the oscillations in an oscillator regulated?
7. How are waves of audible frequencies made to modulate the radio-frequency carrier wave in a broadcasting set?

AREA THREE

How Are Radio Waves Changed into Spoken Words?

When the modulated carrier waves sent out by a broadcasting station strike the receiving antenna, they set up a modulated high-frequency alternating current in the tuned circuit, provided the circuit is tuned to the same frequency. There are at all times many different carrier waves in the air, but only those that have the frequency for which the receiving set is tuned will be heard. By adjusting the variable condensers the receiving circuit is tuned for the station we wish to hear.

True reproduction. The oscillating current in the tuned circuit is rectified and changed into voice current in the plate circuit of the detector tube, in the manner already described on page 753 for the reception of the damped waves. These audio-frequency waves will affect the telephone. The audio-frequency waves are the same in amplitude and frequency as those impressed upon the modulated waves by the voice current at the transmitting station. Hence the same sound is given out by the telephone receiver or loud speaker as was taken in by the microphone. The voice of a singer or speaker or the music of an orchestra comes out of the loud speaker as if the sound originated in the room. Yet it may come from thousands of miles away.

RADIO WAVES CHANGED INTO SPOKEN WORDS

Aircraft telephone receivers. Several kinds of circuits are used in radio receivers of airplanes. The one most generally used is a superheterodyne circuit, shown in the block diagram, Figure 380.

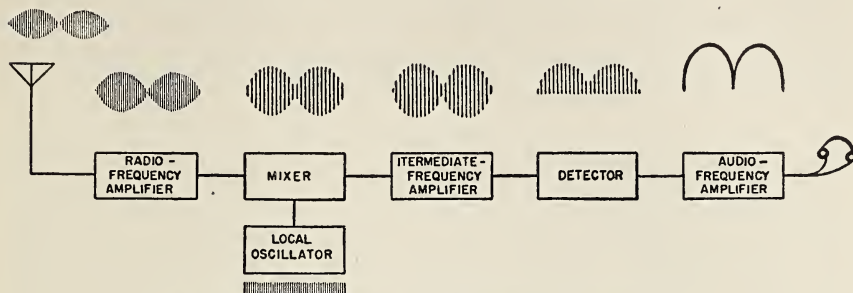


Fig. 380. Block diagram of a superheterodyne receiver.

The superheterodyne circuit uses beat frequency. In order to understand beat frequency the student should review in Unit Six, pages 429 and 430, the formation and explanation of beats produced by a tuning fork.

The voice-modulated radio-frequency waves are intercepted by the antenna and amplified by the radio-frequency amplifier. They are then passed on to a mixer tube. In this tube they are superimposed upon other waves of different frequency, originating in a local oscillator-tube circuit. A beat frequency is produced in this mixer tube just as beats are produced in the ear when two sound waves of nearly the same frequency are mixed. The ear hears both the sound-wave notes and the beat note. Both the radio-frequency oscillations and the beat frequency are passed to the intermediate-frequency amplifier. But the frequency amplifier is tuned to receive the beat, or intermediate frequency, and consequently accepts only one. In many receivers the intermediate frequency is 485 kilocycles.

In order to get a 485-kilocycle intermediate frequency the local-oscillator frequency must differ from the frequency of the radio-frequency amplifier by 485 kilocycles. This result is achieved by tuning the local generating circuit so that the two frequencies always differ by that much.

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After the original wave passes through the intermediate-frequency amplifier, it still has a radio frequency. So it is passed to a detector where it is rectified and reduced to audio frequency, as already explained. The audio-frequency pulsations are passed to the audio-frequency amplifier, and the amplified electromagnetic impulse is changed to sound waves by the vibrating diaphragms of the earphones or loud speakers.

How can a radio set work on the A.C. 115-volt house current? All receiving circuits shown in this unit are used with batteries, an "A" battery and a "B" battery, for the filament circuits and the plate circuits. But the modern radio of the kind we have in our home no longer uses batteries to provide the necessary current. The reason circuits using batteries have been described first in this discussion is because it is much easier to show them in diagram. It is also easier to explain the circuits if batteries are used.

The explanations of radio circuits heretofore given also apply to the "all-electric" radio set plugged in on an A.C. 115-volt house current. In every modern set used on A.C. current there is a tube called the rectifying tube, which changes the alternating current to direct current. This direct current is used in place of the "B" battery. Unfortunately, this rectified current is a pulsating current and produces a hum in the radio. The hum is taken out by using a filter made up of condensers and inductance coils. The currents are used to charge the condensers. As the current is taken from the condensers, it passes through inductance coils, which by self-induction tend to prevent the rise and fall of the currents. Since the plate circuit uses very small currents, the condensers remain charged to a steady potential, and a smooth direct current passes to the plates.

Power supply for aircraft transmitters and receivers. A high voltage is necessary for the operation of aircraft transmitters and receivers. Transmitters require direct currents of from 200 to 1500 volts, depending on the range and power desired. Receivers require from 90 volts to 300 volts.

RADIO WAVES CHANGED INTO SPOKEN WORDS

In most airplanes these high-voltage direct currents are produced from the storage battery by two methods. In one method a vibratory type of induction coil is used for transmitters and receivers of low power. As the magnetically operated vibrator in the primary circuit opens and closes, it causes a higher alternating voltage to be induced in the secondary. This alternating current is rectified by Fleming two-electrode rectifier tubes. The amount of current derived from this arrangement is small, and consequently its use is limited to low-power receivers and transmitters. When greater power in the circuit is desired, a dynamotor is used. An explanation of the dynamotor is given in Unit Ten, pages 640–641.

The currents supplied by both the magnetically operated vibrator and the dynamotor have irregularities that are smoothed out by a filter circuit. This circuit with the condensers C is shown in Figure 381. The coil is an iron low-inductance coil, or choke coil.

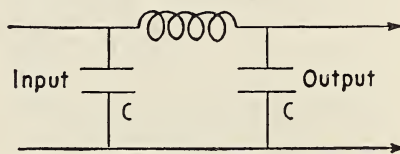


Fig. 381. Diagram of a filter circuit.

Heater tubes. For heating the filaments an alternating current, reduced to low voltage by a step-down transformer, is used. To prevent the A.C. hum in the detector tube, the heating element is electrically separated from a cylinder whose surface becomes the source of electrons. The filament inside is used only to heat the surrounding cylinder to the temperature at which it gives off electrons.

In the discussion of the radio receiving circuits, the audio-frequency currents were shown to act on telephone receivers. But modern radio uses loud speakers to produce sounds. The type of loud speaker used in the first radio receiving sets was essentially a telephone receiver, constructed with a large diaphragm containing a horn to amplify the sound. The weakness of such a loud speaker was that the horn tended to resonate with sound waves of certain frequencies. Therefore, the sounds heard in such a loud speaker were sometimes quite different from

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the sounds originally sent out from the broadcasting station. Improved types of loud speakers, however, were soon devised that would reproduce the original sounds more faithfully.

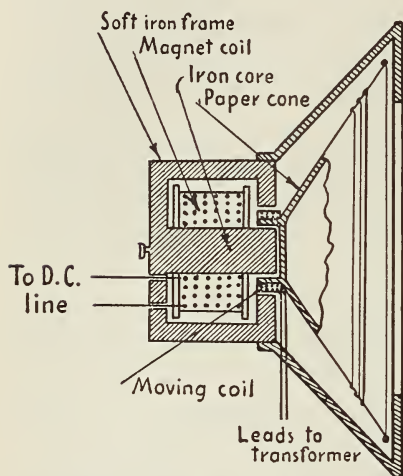


Fig. 382. Cross-section diagram of an electrodynamic loud speaker showing the arrangement of its essential parts.

Electrodynamic speaker. The type of loud speaker generally used is the electrodynamic type, shown in Figure 382. In this loud speaker is a strong electro-magnet which consists of an iron core, a coil of wire in which a direct current energizes the magnet, and an iron cylinder which surrounds both the core and the coil. There is also a small moving coil of wire into which the audio-frequency current of the receiver flows. This coil, which consists of a few turns of wire, is placed over the

end of the core of the magnet, as shown in Figure 382. A very narrow air gap separates it from the core on one side and from the iron cylinder on the other side. When a direct current is flowing through the electromagnet, lines of force from the core to the iron frame are very strong. These lines of force pass through the coil. When a current is received in the moving coil from the output of the receiver, a variable field is set up in the coil. The interaction between this field and that of the electro-magnet causes the coil to vibrate. A diaphragm is attached to the moving coil. This diaphragm is made to vibrate and thus to send out sound waves.

The direct current for the electromagnet is produced by the rectifier tube that supplies the direct current for the detector and amplifying tubes. It is necessary, however, to pass the output of the receiving set through a transformer before it is carried to the moving coil of the loud speaker.

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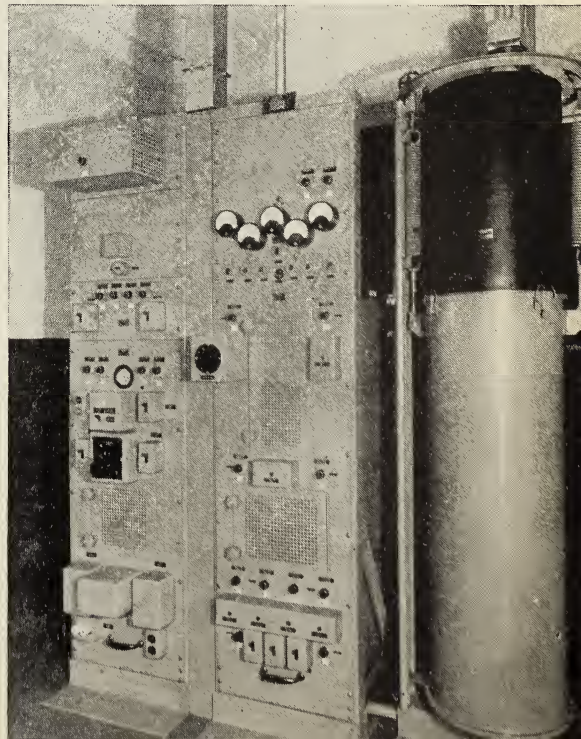
Short waves for radio communication. During recent years the use of very short waves, those below 200 meters, for radio communication has greatly increased. In the beginning these short waves were regarded as useless for transmission purposes because they were believed to be too easily absorbed by trees and houses. Amateur operators and experimenters used them, however, and showed the professionals that they were wrong in regarding short waves as impracticable for transmission purposes. They showed, not only that messages could be sent long distances on short waves, but that much less power was required than in long-wave stations. It was not uncommon, before the war, for the owner of a short-wave transmitter to communicate with other amateurs in a dozen distant countries, all in the course of one evening. The power required is about that consumed by an electric iron. Short waves are used to keep city police headquarters in touch with their patrol cars. Short waves have made possible communication between steamships and their home offices. Large passenger as well as cargo ships are in touch by radio-telephone with either side of the Atlantic throughout their voyages, so that a passenger on any of these ships can telephone to any person in the United States or Europe. At present, short waves are used extensively in broadcasting to and from many foreign countries.

How can a ship locate itself at sea at night or in a dense fog?

Another important use to which radio has been put is direction finding with a coil antenna. In the coil antenna, the ends of a coil of a few turns of wire are connected to the receiving set where the aerial and ground

Three-meter transmitter used in RCA's modern ultraviolet-wave radio circuit.

Courtesy of Radio Corporation of America



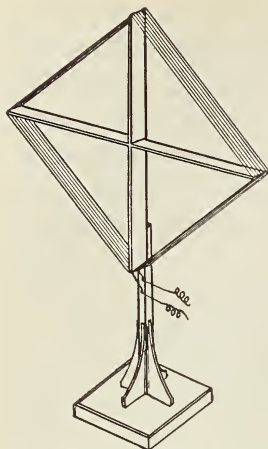


Fig. 383. Diagram of a coil antenna, or radio compass.

wires are generally connected. The coil is usually wound on a square frame, as shown in Figure 383, with a length of three or four feet on a side. It has been found that the signals come in strongest when the plane of the vertical coil points toward the sending station. If the direction of the loop is marked in degrees, the captain can tell his position in relation to the known position of the sending station. By turning the loop to receive a signal from another station whose position is known, the exact location can be plotted.

Government aid to navigation. The government has placed many stations using such antenna along the sea-coasts to direct ships at sea, giving them their location in relation to harbors and obstructions. The ship sends out signals and the compass-station attendant rotates his antenna until the signals are loudest. He then sends his bearings to the ship. With several such bearings from different stations, the master of the ship can plot his location. Airplanes also use the direction-finding power of radio. Compass stations are placed along standard air routes so that in fogs the pilot can fly blindly, guided by the sound and direction of radio signals.

The radio direction finder of an airplane. The radio direction finder of an airplane consists of a radio receiver connected to a loop instead of to an antenna. The loop gives the best reception when the plane of its coil is in the direction of the transmitting station and the poorest reception when the direction of the station is at right angles to the plane of the coil. If the loop is mounted on the outside of the plane where it can rotate through 360° , the angular direction of the transmitting station with relation to the longitudinal axis of the plane can be determined. When a signal is heard, the loop is rotated until the signal fades to a minimum.

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This is called the null position. The direction of the sending station is at right angles to the plane of the loop. The station may be on either side of the loop. However, in practice, the pilot knows the general direction of the station so that this ambiguity need not be considered. The loop direction finder was used in maritime operations several years before its use by aircraft.

The radio direction finder is used by pilots as a homing device. Assuming that the pilot knows which of the two opposite directions mentioned above is toward the station, he directs his flight so that the station signal remains at null and thus brings his plane to the desired destination.

The radio direction finder is used by the pilot to locate his position and to determine how far he is from the station. This is called "establishing a fix." To establish a fix the pilot tunes his receiver until he hears signals from a station which he identifies by means of its identification signal. With his direction finder he obtains the direction (bearing) of that station from his own location. Then he tunes his receiver until he hears a signal from another station and thus determines the bearing of the second station. Having found the bearing of his location from each station, the pilot can now draw lines on charts specially prepared for direction finding and determine his location at the intersection of the direction line of the two stations.

Radio compass. Though the direction finder described is sometimes called a radio compass, strictly speaking a radio compass has a fixed loop attached to a visual indicating instrument. In one type the hand on the dial remains centered when the plane is headed directly toward the station, and moves either to right or to left when the plane deviates from that direction. In another type the dial is graduated into 360° and shows the bearing of the station from the plane.

Flying the radio beam. The Civil Aeronautics Administration has established a number of radio-range stations in the country to help the pilots of airplanes fly to their destinations. From

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these stations radio signals are broadcast at frequencies from about 200 to 400 kilocycles. Each station has its own set wave length. By the use of loop antennae these signals can be directed. A loop antenna can be used for directional reception and transmission, a property that makes it valuable in range-beacon work. Transmission and reception are strongest in the direction toward which the antenna points. At right angles to its plane, transmission and reception are nearly zero.

Two loop antennae are used at right angles to each other, thus dividing the space around the station into four quadrants. A radio transmitter sends audio-frequency modulated waves first over one loop and then over the other by an automatic motor-driven switch. First it sends the Morse character *N*, a dash and a dot, over the *N* antenna and then the character *A*, a dot and a dash, over the *A* antenna. The current is switched from loop to loop in intervals that make the two signals fit into each other. When they are heard together, the pilot cannot distinguish them and therefore he hears a continuous signal.

The two men in this picture are operators in a radio-range station. Part of their job is to send out the radio signals which keep pilots on their courses as they "fly blind."

Courtesy United Air Lines



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Figure 384 shows the *N* and *A* quadrants. If a pilot is flying in an *N* quadrant he hears only the *N* signal. If he is flying in an *A* quadrant he hears only the *A* signal. But if the plane enters the shaded area within two intersecting quadrants both the signals *N* and *A* will be heard. One will predominate depending upon which quadrant the airplane is in. If the airplane is within the two radio-beam lines shown in the figure, the pilot will hear only a continuous hum. By this he knows that he is on the beam and on the course that will take him straight to the station.

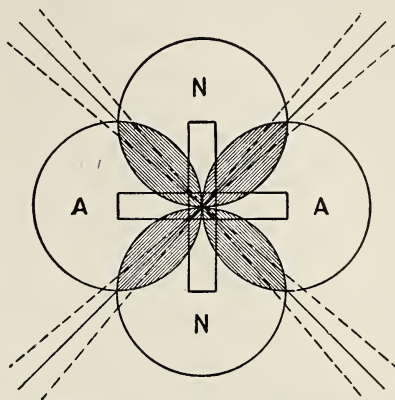


Fig. 384. Diagram showing pattern of field strength about a loop radio-range station that sends radio-beam signals to airplanes.

Charts are issued which show the network of stations and the direction of their beams. Each radio-range beam pattern is shown in pink on the aeronautical charts. On each beam the directions toward and away from the station are given, together with the frequency number of the station and the station-identification letters. The signals are interrupted each half-minute to give the station-identification letters. Through this means the pilot may be sure of the station from which signals are coming.

The loop-type station is entirely satisfactory for daylight flying, but certain weaknesses in transmission make the signals unreliable at night. However, they are satisfactory within a radius of 30 miles. Therefore, loop-type transmission is used by many stations where distances in excess of 30 miles are not involved.

With the loop-type station it is not possible to transmit both range signals and weather reports simultaneously. In order to transmit weather reports it is necessary to discontinue the range signals and operate the whole system as a radiotelephone. While this may benefit one group, another group of aircraft may be flying by instrument and depending on the uninterrupted range-

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beacon signals for their navigation. The request by pilots for uninterrupted range signals led to the development of a more

efficient system, which broadcasts range signals and radiotelephone messages simultaneously on the same frequency.

This system uses four vertical towers 120 feet high placed at each corner of a square 600 feet on a side, as shown in the diagram, Figure 385. Each pair of towers diagonally opposite each other produces the same effect as was produced by the cross loops. In the center of the square is a fifth tower which operates a conventional antenna. Figure

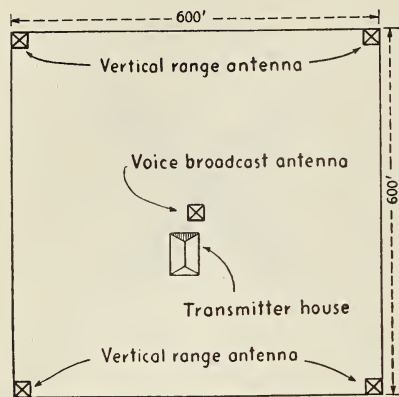


Fig. 385. Diagram showing parts of the tower arrangement in a radio-range station.

386 represents the field patterns radiated by the system. The largest circle represents the field of the central broadcasting tower.

The central tower sends out continuous radio-frequency carrier waves whose frequency is that assigned to the station. The two diagonal pairs of towers send out the *N* and *A* signals at a frequency 1020 cycles higher than that of the central station. When the receiver in the airplane is tuned to the station frequency, both the signals from the central tower and the *N* and *A* signals from the corner towers are received. The difference of 1020 cycles develops a beat note of 1020 cycles in the receiver, as explained on page 765. This beat note will be detected, amplified, and heard in the ear-phones. When radiotelephone

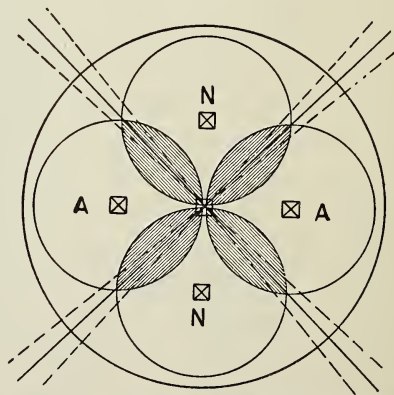


Fig. 386. Pattern of field strength about the four range towers and the central broadcasting tower in a radio-range station.

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messages are to be broadcast, the carrier wave from the central tower is modulated by the voice frequencies, as explained on page 765. The voice-modulated wave is intercepted by the receiver in addition to the beat frequency carrying the *N* and *A* signals. It is thus possible by concentration for the pilot to select either the *N* and *A* or the voice signal, as needed at the moment. However, the two can be separated by the filter action of an arrangement of inductances and capacitances, and by a switch system. These provisions make it possible for the pilot to hear range signals while at the same time the copilot is listening to the radiotelephone message.

To fly the beam, the pilot tunes his receiver to the station-frequency number and listens for the signals and the station-identification letters. He notes the direction of the beam and then directs his plane so as to merge his course with the beam. To fly the middle of the beam, the pilot keeps the continuous tone which is his on-course signal in his earphones. When out of the course with the *N* quadrant to his right, he hears the *N* signal. Then he knows he is to the right of the beam and so turns to the left. If he hears the *A* signal he knows he is to the left and so turns to the right. If he is right on the beam he continues his flight straight ahead.

Directly over the radio-range transmitter is a cone of silence caused by the interference of the waves. When the pilot is nearing the station the signals grow louder and then suddenly stop. This means that he is directly over the transmitting station.

Radio altimeter. On page 417 of Unit Six, we described a sonic absolute altimeter which indicates the height of the airplane above the ground by the reflection of sound waves. Another instrument, the radio altimeter, makes use of electromagnetic wave reflection to detect altitude. The velocity of a radio wave is so great that it is difficult to measure the time interval between a direct signal and its echo. For heights less than a thousand feet the time interval is less than two millionths of a second. The method used to measure this time interval is as follows: A radio trans-

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mitter in an airplane sends down to the earth a frequency-modulated signal with frequency changes at a definite rate with respect to time. The signal is reflected by the earth after a time interval which is equal to twice the height divided by the velocity of the wave. During this time the frequency of the transmitter signal has changed and now differs from the frequency of the echo by an amount that is equal to rate of change multiplied by the time interval. The reflected wave and the outgoing wave

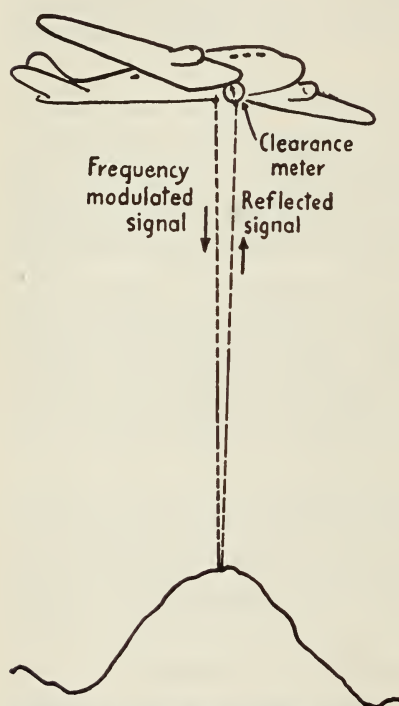


Fig. 387. Diagram illustrating the operation of the radio altimeter apparatus.

are combined in the plane's receiver. Figure 387 illustrates diagrammatically the transmission and reception of the signals. Since they differ in frequency, a beat note is produced (see page 765) that is measured by a frequency meter, called the clearance meter. Since the difference in frequency is proportional to the time taken by the echo, the reading of the meter is also proportional to the time and to the height. The meter is calibrated in feet. At the take-off, when the airplane is 50 or more feet off the ground, the clearance meter will register. As the airplane rises higher the pointer moves to show the increasing distance to the ground. In cross-country flying, the meter will show the variations in the

contour of the earth. From the information thus obtained and a contour map of the region the pilot can locate his position with respect to the earth when flying above the clouds.

The altimeter will indicate to the pilot his height above the ground directly beneath him when he is making an instrument

landing at an airport, or when he is breaking through clouds. As he descends, the indicator registers his decreasing altitude until his landing wheels are very close to the ground.

Bonding and shielding. The radio equipment used in aircraft must have extreme sensitivity in order to operate with small antennae. Receivers with a high degree of sensitivity are very susceptible to the interference caused by the electrical equipment of the airplane and the interference set up by discharges of static electricity between adjacent metal parts of the aircraft. Where metal plates are joined, sparks are liable to occur. These sparks produce strong interference in the receivers, destroying their efficiency. To eliminate this interference, the joints are bonded and the electrical equipment is inclosed in a metal shield.

ANSWER THESE QUESTIONS

1. What is actually happening in a radio set when it is tuned to some particular station?
2. How is the A.C. hum eliminated in the modern radio set?
3. How does a loud speaker differ from a telephone receiver?
4. Describe the sequence of changes of energy from a voice in a broadcasting studio to the reproduction of that voice in your home.
5. What particular advantages do short waves have over long waves for radio purposes?
6. How does a radio direction finder operate?

AREA FOUR

How Has Television Been Made Possible?

We have become accustomed to the transmission of sounds over great distances. But the discovery that it is possible to see things over a great distance fills us with wonder. That it is possible is no longer a speculation but a demonstrated fact. In 1927 a system of television was first publicly demonstrated in this country, and in 1928 regular broadcasting by television began both in this country and in England.

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Difficulties to be mastered. Large sums of money and a great many years of patient investigation have been expended to bring television to its present stage of development. To understand why it has taken so long a time and so much money, it is necessary to understand some of the difficulties that had to be overcome. In moving pictures 24 separate pictures are shown per second, but each picture is seen as a complete unit. In television, 30 pictures per second are shown, but each picture must be dissected into several hundred thousand tiny points of light that must be conveyed over the transmission system. This complication explains why television is so difficult. For transmission these points of light must be changed to electric impulses of very high frequency. At the receiving end these electric impulses must be changed back to points of light to reconstruct the original picture. To accomplish this several different systems have been developed.

The system of television demonstrated by the Bell Engineering Laboratories in 1927 included a mechanical scanner to dissect the picture into minute points of light, a photoelectric cell to change the points of light into electric impulses, and, at the receiving end, a neon tube to change the electric impulses back into minute points of light.

The electric eye. A photoelectric cell makes use of the effect of light on electrical charges. The cell is a vacuum tube. A wire is led into the tube and connected to a plate coated with potassium or cesium, which are sensitive to visible light. Another wire is connected to a ring or plate of an inactive metal like nickel or platinum. The metal potassium emits electrons when light falls

upon it, the number being directly proportional to the intensity of the light. When we connect the photoelectric cell in series with a battery and a galvanometer, as shown in Figure 388, the current flowing through the galvanometer fluctuates as the inten-

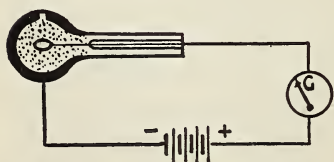


Figure 388. Photoelectric cell.

sity of the light focused on the photoelectric cell varies. The current is very feeble, but can be amplified by vacuum-tube amplifiers. When the cell is not illuminated, no current flows, showing that the circuit is completed by the flow of electrons in the vacuum tube.

The uses of the photoelectric cells are innumerable. They are used in photometry for measuring the brightness of lamps. They are used in burglar alarms and in fire alarms. Since the cells convert light energy into electric current, their possibilities are great. They have made sound pictures possible. They are used in television and for sending pictures by wire for newspapers.

The neon tube. The neon tube is a glass tube with wire sealed in the ends and connected to two electrodes. It is filled with neon gas at low pressure. When voltage is applied to the lead-in wires, a reddish glow is seen in the tube. This tube is valuable for television because it responds with marvelous rapidity to slight changes in the voltages applied to it. The variations of voltage coming to it from the sending station produce the same variations of light that affect the photoelectric cell.

The method devised by the Bell Telephone engineers involves a rotating disk with seventy-two holes arranged in a spiral pattern, behind which is a very intense light that passes through the holes of the disk and strikes the object. The disk rotates eighteen times per second, and the seventy-two beams of light strike the object in one revolution. These seventy-two beams of light are reflected to the photoelectric cells, which set up currents of electricity that vary with the intensity of the reflected light. The currents are feeble and must be amplified before transmission.

The receiving apparatus consists of a neon lamp, an amplifier, and a rotating disk. The light in the neon tube varies with the variation in current from the photoelectric cells. The amplifier strengthens the current from the photoelectric cells. The rotating disk turns with such great speed that the images follow one another in less than one-sixteenth of a second, the duration of vision, and the entire picture is seen at one time.

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Picture transformed into electric impulses by the iconoscope. The next step in the development of television, especially for commercial purposes, was the electronic method of scanning. This method employs two tubes, the iconoscope, or device at the sending end of the set, and the kinescope at the receiving end. The iconoscope is a dipper-shaped vacuum tube which transforms a picture into electric impulses. This tube contains a sensitive mica electrode or screen dotted with millions of silver globules coated with cesium. When an image falls on the screen, the light waves from the image cause the silver globules to give off electrons, as in a photoelectric cell. The quantity of electrons given off by different parts of the screen depends on the quantity of light coming from the image. The electrons which leave the screen are attracted by a positive charge on another electrode in the iconoscope. Thus the sensitive plate acquires a deficiency of electrons, and through this deficiency sets up a pattern of the light and shadows in the scene to be transmitted.

The iconoscope, invented by Zworykin of RCA, is the apparatus that takes the television picture. Back of the tube is a microphone, with which we are all familiar.

NBC Photo

The arm of the iconoscope, or the handle of the dipper-shaped tube, contains an electronic gun or hot filament which shoots a stream of electrons on the sensitive screen. The electronic gun supplies electrons to the silver globules to take the place of the electrons that they have lost. Whenever an electron from the gun reaches a globule, a tiny surge of electricity passes to a condenser plate back of the screen. This surge and the surges from other globules are amplified about a million times, thus producing variations of current which are transmitted by wire or imposed on radio carrier waves



radiated from antennae. In other words, the scene is transformed into a succession of electric impulses that must be changed back into a picture at the receiving end of the apparatus.

Electric impulses transformed into a picture by the kinescope.

The kinescope, or device at the receiving end of a television set, is a large funnel-shaped vacuum tube. At the large end of the tube is a glass screen painted with a crystalline powder that glows strongly when struck by electrons. At the small end of

the tube is an electron gun for shooting a beam of electrons against the fluorescent screen. This thin spray of electrons can be played up and down and from side to side over the screen by electromagnets, as in the iconoscope. If the beam is vibrated from side to side very rapidly, this spot of light caused by the beam of electrons on the screen is seen as a streak of light. Thousands of these streaks of light can be produced in a second, and if 525 of them are laid side by side so as to cover the whole screen, it appears covered with a glow of light. This is repeated 30 times in a second. The variations of the current coming from the transmitting station regulate the width of a slit which determines the number of electrons in the beam, and this adjusts the brightness of any part of the screen. The beam is kept moving across the screen in exact synchronism with the movement of the iconoscope beam over its screen. This is done by synchronizing impulses sent out by the transmitter. The signals coming from the iconoscope, produced by the variations of light on the image it is scanning, increase and decrease the flow of electrons in the kinescope and produce the same lights and shadows. These lights and shadows produce an



RCA Victor Photo

The largest and smallest tubes used in RCA Victor television receivers. The big one is a 12-inch kinescope on which images are reproduced.

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exact image on the screen of the object at the transmitter, which has been transformed into impulses by the iconoscope.

Other forms of the camera tube are used, but the principle of electronic scanning is used in most of them. Improvements of the iconoscope described above have been made. One form is called the orthicon, which uses electrostatic plates to control the electron beam. It has a different form, being a straight tube. The scene is thrown on one side of a translucent mosaic, while the electron beam scans the other side. Today television has progressed to the point where companies are seeking licenses for commercial broadcasting. Also television receivers compare favorably in price with radio receiving sets of a few years ago.

Sending pictures by wire. This process, used extensively by newspapers, works on the same principle as television. The photographic print is placed on the cylinder of a wire-photo sending machine. The cylinder revolves 100 times per minute and moves laterally one inch each minute. It is scanned by a pencil of light and reflected to a photoelectric cell. The variations of light and shade cause the cell to set up varying electric impulses that send currents out over the wire-photo circuit. These currents correspond to the variation of light and shadow in the picture scanned. The currents change the width of a slit through which light is thrown on a photographic film placed on another cylinder in a wire-photo machine which moves in exact synchronism with the cylinder in the scanning machine. Thus the picture is printed as an exact copy of the original.

The electron microscope. The electron microscope, as its name indicates, is a device which magnifies objects through the movement of electrons. This microscope closely resembles a kinescope, having two cylindrical anodes positively charged with reference to an electron-emitting cathode or electron gun. Each anode contains a punctured diaphragm. A grid controls the number of electrons that leave the cathode, and the anodes bring the electrons into nearly parallel beams. The object to be magnified is

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placed in the path of the parallel beams. The electrons from the beams pass through the object and are focused by electron lenses on a fluorescent screen. Thus the magnified image may be viewed on the screen or may be photographed by a camera.

An optical microscope, because of the wave length of light, can be used to magnify only about 1000 diameters. In contrast with this limit, an electron microscope has been built that magnifies 100,000 diameters. This microscope, however, is not practical for commercial purposes because it requires a vacuum tube from 7 to 10 feet high. A more practical model, which requires a much smaller vacuum tube, magnifies 10,000 diameters. The magnification of an electron microscope is greater than that of an optical microscope because of the extremely short wave lengths set up by the electrons passing through the object.

ANSWER THESE QUESTIONS

1. What are the essential parts of a photoelectric cell?
2. What are several possible uses for photoelectric cells not mentioned in the text?
3. What property makes a neon tube invaluable in television?
4. How does the iconoscope change a picture into electric impulses? How does the kinescope change impulses into a picture?
5. Why is the picture continuous on a television screen?
6. What is an electron microscope? How does its magnification compare with that of an optical microscope?

AREA FIVE

How Can We See through Opaque Objects?

Let us now consider waves that are very much shorter than ultraviolet waves. We know them as X-rays. Fortunately, a great deal is known about how these waves are produced and about their characteristics. X-rays have been of much interest because they have made it possible for man to see through opaque objects. Because of this property, they have been of great value to medical science and to the commercial arts and industries.

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Electrical discharges in a vacuum. To observe discharges of electricity in a vacuum tube let us set up apparatus including a

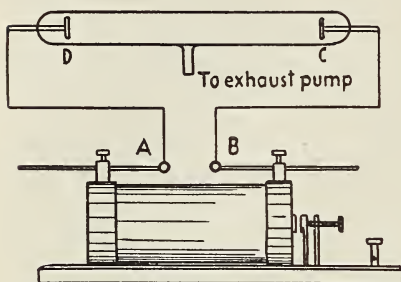


Fig. 389. Arrangement of apparatus for observing electrical discharges in a vacuum.

vacuum tube and an induction coil as shown in Figure 389. When we fill the tube with air at ordinary pressure, a discharge takes place between *A* and *B*, but no discharge occurs between *D* and *C* because they are farther apart. Now let us exhaust air from the tube and continue to maintain a high difference in potential between *D* and *C*. When

we have reduced the pressure within the tube to about one-eighth of an atmosphere, we observe a discharge between *D* and *C* in the form of a ribbon of reddish light. If we continue the exhaustion, the writhing, snakelike arc turns into a reddish glow filling the whole tube.

With further exhaustion, the reddish glow recedes toward the anode *D*, leaving a glow around the cathode *C* and a dark space in the center. With still further exhaustion the red glow recedes farther toward the anode and breaks up into striations, alternate streaks of light and dark. The glow near the cathode has expanded and is separated from the cathode by a dark space. The resistance of the tube has been decreasing as the pressure in the tube is made smaller. But the resistance begins to increase again when the pressure has been reduced, until the striations near the positive electrode have about disappeared and the dark space at the cathode has increased until it nearly fills the tube. The only light now seen does not come from inside the tube, but is a greenish fluorescence from its glass walls.

The Geissler tube. The tube used in the above experiment is known as a Geissler tube. In the preparation of this tube the air is removed and another gas is substituted for the air at the low pressure of about one centimeter of mercury. When the tube

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is attached to an induction coil, ionization occurs within the gas, causing it to glow. The color of the glow depends upon the gas that is substituted for air in the tube. The Geissler tube is widely used for advertising purposes, especially in neon signs, so named because neon gas is used.

Cathode rays. When the vacuum tubes are exhausted to a pressure of 0.001 mm. of mercury and the dark space from the cathode has filled the tube, an invisible radiation called the cathode ray is given off from the cathode at nearly right angles to the surface, Figure 390. The presence of these cathode rays may be detected (1) by their heating effect, (2) by their fluorescent effect, (3) by the shadow they produce, and (4) by their mechanical effect. If the surface of the cathode is hollowed out so as to form a part of the surface of a sphere, these rays are focused at the center of the sphere. A piece of tungsten placed at this focus becomes white hot in a short time.

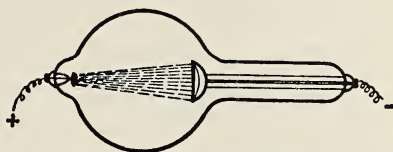
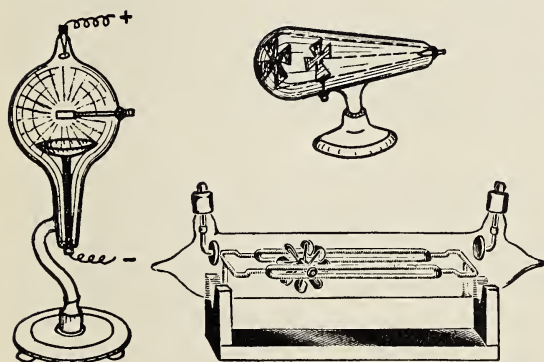


Fig. 390. A cathode tube.



Courtesy Central Scientific Co.

Fig. 391. Cathode tubes for demonstrating heating, fluorescence, direction, and propulsive force of cathode rays.

Such an arrangement is shown in the tube to the left in Figure 391. A tube containing a Greek cross shows the fluorescent effect of the ray by the greenish glow of the tube. A shadow of the cross at the end opposite the cathode proves that these rays go out in straight lines from the cathode. In the tube

at the lower right is a light wheel having mica vanes and so adjusted as to roll on smooth glass rails. If the cathode rays are

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directed against the top vanes of the wheel, it rolls along the rails as if bombarded by a stream of minute bullets. This shows that the rays impart momentum to a target in their path.

Magnetic effect on cathode rays. The following experiment shows strong evidence for the theory that cathode rays are streams of negatively charged particles. The tube shown in Figure 392 has

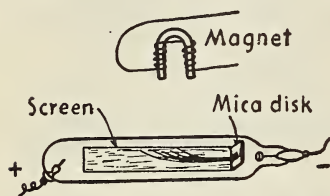


Fig. 392. Cathode rays are deflected by a magnetic field.

a mica disk with a slit in it placed in front of the cathode electrode and a screen which has been coated with some substance such as zinc sulfide which fluoresces strongly when cathode rays fall upon it. The mica disk absorbs all cathode rays that strike it except those which pass through the slit. Where these fall upon the screen

they produce a line of light because of the fluorescence. If a magnet is held in the position shown in Figure 392, this beam of light is deflected, showing that the cathode rays are deflected in the direction to be expected if they were negatively charged particles moving away from the cathode. This stream of moving, negatively charged particles constitutes an electric current, as we have learned, and the effect of a magnetic field upon it should be the same as its effect on a current of electricity.

The nature of X-rays. In experimenting with vacuum tubes shortly after 1875, Crookes and others had seen that cathode rays produce a greenish fluorescence in the glass when they strike something like the end of the glass tube. For a long time, however, no one discovered that another sort of radiation is produced when these rays strike against an object. It was not until 1895 that William Roentgen noticed that a fluorescent screen outside of the tube shone out with vivid brightness when the cathode glow was produced in a high vacuum tube. He covered his tube so that none of the glow inside was visible, and yet the screen outside continued to shine in the darkness with the new strange light.

The rays of this light he called X-rays, because he did not know what they were. They are sometimes called Roentgen rays.

X-rays are like cathode rays in that they produce fluorescence. That they are not cathode rays is shown by the ways in which they differ from cathode rays. X-rays will pass through many substances, like glass, that cathode rays will not pass through. X-rays are not deflected by a magnetic field or an electrostatic charge and do not carry an electrical charge. That they are waves like light waves, but very much shorter, has been shown by the fact that a kind of reflection, known as interference reflection, can be produced with them. To do this, advantage was taken of the regular arrangement of molecules in crystals to form a diffraction grating. By this means it was shown that X-rays do produce interference and are, therefore, waves like light. Their wave lengths vary from 0.0000000017 to 0.0000075 centimeter.

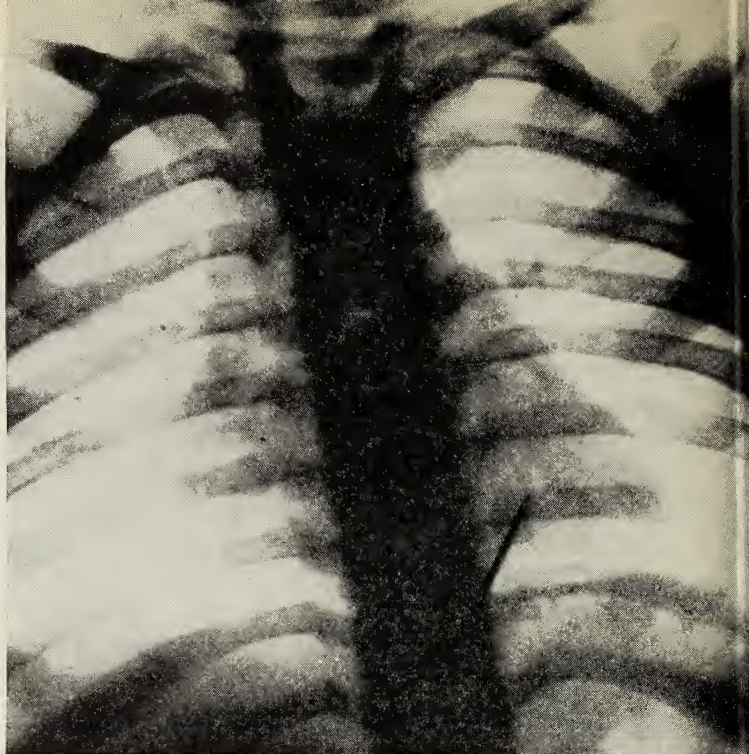
X-rays, like cathode rays, have the property of causing any electrified body on which they fall to lose its charge. If a charged electroscope is placed near an X-ray tube, the leaves at once begin to close. The X-rays, in passing through a gas, release electrons from the molecules of the gas, and these electrons fill the gas with electrically charged particles, the electron being negatively charged and the atom that has lost the electron being positively charged. The charge on the electroscope attracts the particles that are oppositely charged and is thus discharged.

The property that X-rays have of penetrating certain substances makes it possible to take photographs on a sensitive plate, which are unlike photographs taken in visible light in that they are shadow photographs. Some X-ray pictures are shown on the following page. Such photographs are of considerable value in medical science.

The production of X-rays. As has been shown, X-rays are produced whenever the velocity of cathode rays is changed. They are produced, like all electromagnetic waves, by the motion of electrons. They are produced in tubes that are similar to cathode-ray tubes. In fact every cathode-ray tube is also an X-ray tube.



Ewing Galloway



Century Photos, Inc.

The X-ray picture on the left shows the bone structure of the wrist and hand. The one on the right shows the location of a safety pin that has been swallowed by the patient.

X-ray tubes. Tubes designed to produce X-rays have a tungsten or platinum disk placed in a cathode-ray tube in such a position that the cathode rays are concentrated upon it. Such a tube is

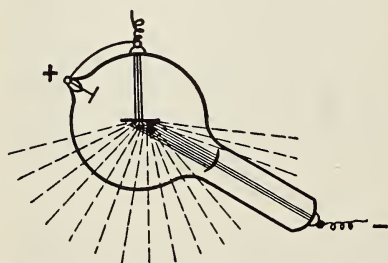


Fig. 393. Diagram showing radiation from a cathode-ray tube with platinum disk.

shown in Figure 393. The electrons that strike the disk set up the invisible radiations known as X-rays. The penetrating power of the rays differs, depending upon the degree to which the tube producing them is exhausted and upon the voltage used. The rays from a high-vacuum tube are very penetrating and are

called hard X-rays. The less penetrating rays produced by a tube with comparatively low exhaustion are called soft X-rays.

WE CAN SEE THROUGH OPAQUE OBJECTS

One form of X-ray tube, known as the Coolidge tube, is especially effective in producing X-rays. This tube has a high vacuum, so high that no current will pass through, even when a high voltage is applied. The cathode of the tube, as shown in Figure 394, is a very small filament, somewhat like the filament of an audion tube. When the filament is heated, the high voltage causes electrons to be driven against a heavy metal target, thus producing a steady flow of X-rays.

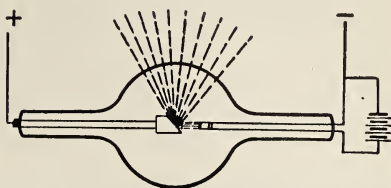


Fig. 394. Cathode-ray tube with filament.

The fluoroscope. Thomas Edison devised a means to show the effects of X-rays without photographing them. It is called a fluoroscope and is made in this way. The sides of the box shown in Figure 395 are opaque. The screen is coated with barium platino-cyanide which is sensitive to the fluorescent effects of the X-rays. Such a screen, it will be remembered, was used by Roentgen. If the hand is held between the fluoroscope screen and the X-ray tube, the bones of the hand can be seen. With this device a doctor can examine the vital organs of the body.

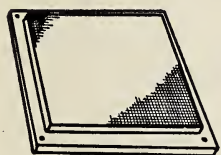
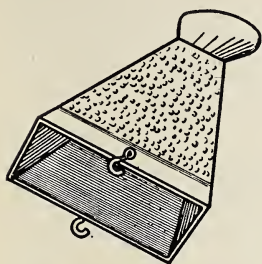


Fig. 395. The fluoroscope.

The uses of X-rays. Some of the uses of X-rays have been shown. The X-ray picture and the fluoroscope have enabled physicians to diagnose the ills of humanity with an accuracy that would have seemed miraculous fifty years ago. X-rays are used in

determining whether paintings are the work of the old masters or copies. They are used in determining the condition of materials employed in airplane construction. They show faults such as air pockets or invisible cracks in car wheels and rails used in

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railroads. Steel mills today have X-ray laboratories. Jewelers use X-rays to tell gems from their imitations. Space is wanting to tell about the many uses to which X-rays have been put. But X-rays can also be used in a dangerous way. Long exposure to them sometimes causes severe burns. They should be used only by those who are skillful in handling them and who understand the proper precautions to be taken.

High-voltage X-ray tubes. To secure rays of still greater penetrating power, as for treating cancer, scientists use X-ray tubes 12 to 15 feet high, to which one, two, or even three million volts can be applied. "Millions of volts" sounds dangerous, but the patient is in no danger of an electric shock, for the X-ray machine is kept in a room above the patient, the X-rays being sent to his room through a tube. With a modification of the electrostatic generator devised by Dr. Trump of the Massachusetts Institute of Technology, 4,000,000 volts can be supplied whenever tubes are made that can take this high voltage safely. With such tubes, doctors have a means of applying rays that are not only more effective but much cheaper than those obtained from radium.

ANSWER THESE QUESTIONS

1. What causes the reddish glow when an electrical discharge passes through a partially evacuated tube?
2. What is a neon sign? What kind of tube is used in a neon sign? What is the advantage of such a tube?
3. What do you understand by cathode rays? What evidence supports the theory that these rays are streams of negatively charged particles?
4. What are X-rays? How do these rays resemble cathode rays? How do they differ from cathode rays?
5. How do hard X-rays differ from soft X-rays? Which of these rays are more penetrating?
6. How does a Coolidge tube produce X-rays? How does it differ from the usual X-ray tube?
7. Why is a fluoroscope especially useful? What process did the invention of the fluoroscope eliminate?

AREA SIX

What Have Scientists Learned from the Breaking Up of an Atom?

Let us now discuss waves still shorter than X-rays, or waves given off by substances called radioactive substances. These waves are especially important because they provide a new basis for exploring the nature of matter. At present many scientists are working with radioactive substances and doubtless within the near future will reveal much valuable information.

Alpha, beta, and gamma rays. In 1896, one year after the discovery of X-rays, a French scientist named Henri Becquerel discovered that rays from uranium salts would pass through black paper and affect a photographic plate. His discovery attracted the attention of the best-known scientists of that time, including the noted Curies, Pierre Curie and his wife, Marie. The Curies examined a ton of uranium and found that it contained two remarkably radioactive substances called radium and polonium. These radioactive substances accounted for the new Becquerel rays.

In 1899 Professor Rutherford of Canada found that Becquerel rays consist of three kinds of radiation, and he isolated three rays which he named alpha, beta, and gamma rays. The alpha rays are positively charged particles with each particle carrying two positive elementary charges; that is, each of the

The distinguished scientist in this picture is Madame Curie, who spent a large part of her life isolating the rare and miraculous element known as radium.

Keystone View Co.



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particles has lost two electrons. The mass of these particles is about four times the mass of the hydrogen atom. Rutherford

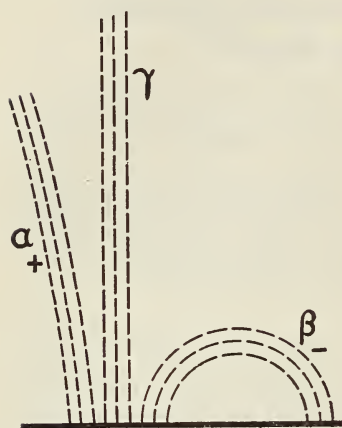


Fig. 396. Electrostatic separation of alpha, gamma, and beta rays.

proved that these particles are positively charged helium atoms. He found that the beta rays are exactly like the cathode rays. They are electrons ejected in streams with velocities of from 60,000 to 180,000 miles per second. Their penetrating power is much greater than that of alpha rays. The electrostatic field deflects beta rays in a direction opposite to the direction of deflection of alpha rays, as shown in Figure 396.

The gamma rays are not deflected by the electrostatic field, as shown in the diagram, or by a magnetic field.

They are electromagnetic waves similar to or identical with X-rays and of much greater penetrability than alpha or beta rays. They are shorter and, like X-rays, they are thought to be caused by the impact of the beta rays on particles of matter.

The radioactive elements. Rutherford was the first to announce that the atoms of uranium, radium, and other radioactive substances were continually exploding and changing to atoms of lower atomic weight. For some reason not now understood, some atoms are stable and have a long existence, whereas others are less stable and have a brief existence. For example, a radium atom, which has 226 times the weight of a hydrogen atom, explodes after an average life of 2500 years. When it explodes, it loses an alpha particle which becomes an atom of helium when it loses its positive charge. The remainder of the atom, 222 times the weight of the hydrogen atom is a gas known as radon. The average life of a radon atom is 3.85 days. When the radon atom explodes it gives off an alpha ray and changes into a solid substance known as radium A, whose atomic weight is 218. The

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explosions continue, each atom having a lower atomic weight if alpha particles are thrown off. If gamma and beta rays are thrown

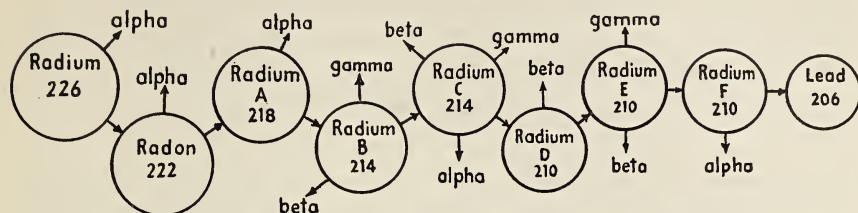


Fig. 397. The above diagram illustrates the successive stages in the breakdown of the radium atom resulting from explosion. Each explosion causes rays to be thrown off.

off, however, the atomic weight is unchanged. This disintegration of atoms continues as in the diagram, Figure 397, until a stable atom without radioactive properties is found. This remaining, stable atom is probably lead.

Atomic energy. We have just been discussing the explosion of atoms, wherein certain particles of the atom fly off, reducing its weight and changing its character. Let us consider now the energy resulting from this disintegration of the atom. What is the force that sends alpha particles flying from the atom at a speed of from five thousand to twenty thousand miles per second? The energy that flings them out must exist somehow within the atom itself. The tremendous speed with which the particles are projected is evidence that there must be an immense supply of intra-atomic energy.

Some of the uses of radium. One of the many commercial uses of radium is the manufacture of radium paint, which is applied to figures on the dials of compasses, watches, clocks, and other similar devices in order to make them visible in the dark. A small quantity of radium, mixed with zinc sulfide and varnish, provides a fluorescent paint that is not visible in sunlight or artificial light but can be seen in the absence of light. Radium is used in the cure of cancer. For this, radon, the first emanation of radium, is used. Radon is collected by dissolving a salt of radium in water.

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Radon gas is given off from this solution. Workmen screened behind lead plates and using long tongs prepare tubes of this gas. These tubes are small and sharp-pointed so that they can be embedded in a growth and left for a short time. While the radiation from radon lasts only for a short period, injury may be done to normal tissue if the radon tube is left in the tissue too long.

Cosmic rays. The existence of rays coming to us from outer space has long been known. The explanation of the rays is not certain, but scientists are inclined to the view that they are radiations of energy from the disintegration of particles called mesotrons that are created by the action of protons coming toward the earth from interstellar spaces. Some of the mesotrons thus created disintegrate in the upper reaches of the atmosphere, giving off electrons that travel erratically. Other fast-moving mesotrons travel far toward the earth before disintegrating and discharging electrons. The wave length of cosmic rays is estimated to be from 0.00000000000032 centimeter to 0.00000000000525 centimeter, much shorter than the wave length of the gamma rays. Their power of penetration is very great. Much research is being carried on at the present time to discover more about cosmic rays. By such research scientists hope to discover more about the structure of atoms.

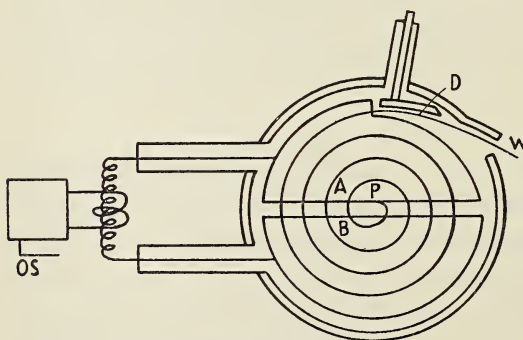


Fig. 398. Diagram of the Lawrence cyclotron.

The cyclotron. The cyclotron is a machine devised to bombard the atom and break up its positive nucleus. Figure 398 is a diagrammatic sketch of a cyclotron invented by Dr. David Lawrence of the Univer-

sity of California. This notable machine consists of a cylindrical box placed between the poles of a large electromagnet. When a

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vacuum is produced in the box, a high-frequency oscillator sets up a potential of 50,000 volts between the electrodes on the opposite sides of the box. Deuterons, or the nuclei of heavy hydrogen atoms, are admitted to the box, where the high potential between the electrodes moves them outward, and the magnetic field between the poles of the electromagnet causes them to move in a circular direction. As the voltage reverses through each half-circle, the particles receive new impulses which cause them to spiral outward and strike a beryllium target at the rim of the box.

The fragments of an atom produced by the cyclotron are studied by means of a cloud chamber invented by Wilson, an English scientist. This chamber, one side of which is of glass, is filled with dust-free air saturated with water vapor or alcohol vapor. When the saturated vapor is cooled by sudden expansion, it tends to condense, according to the principles of condensation. If an alpha or a beta particle is shot through the chamber and sudden expansion occurs, it pushes the electrons from a series of atoms and produces charged ions. Vapor clings to each ion and a droplet of water forms around the ion. The path of the ion is made visible by light reflected from the droplets of water.

The smashing of the atom has brought about a changed idea of its structure. Formerly the atom was supposed to consist of two kinds of particles, protons and electrons. In 1932, however, an English scientist, James Chadwick, discovered the neutron, and Carl Anderson of the California Institute of Technology discovered the positron. The neutron, which is a little heavier than the proton, is found in the nucleus and carries no charge of electricity. The positron, which has about the same weight as a negative electron and is the ultimate unit of positive electricity, is found in the nucleus and carries a charge of positive electricity. In view of these findings, the nucleus of an atom is now supposed to contain neutrons and positrons, as well as protons. At present scientists are uncertain whether the proton is a neutron that has lost an electron, or the neutron is a proton that has gained an electron. As investigation continues, scientists are certain to clear up this uncertainty.

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ANSWER THESE QUESTIONS

1. What is meant by Becquerel rays?
2. How did Rutherford discover that Becquerel rays were made up of three different kinds of rays?
3. What are the alpha rays? Do they carry a charge?
4. What are the beta rays? What kind of charge do they carry? What is their speed?
5. Why are gamma rays not affected by an electrostatic field?
6. What do the gamma rays resemble most? How were the gamma rays set up?

SUMMARY

Electromagnetic waves are set up in ether. In order of wave lengths, they include radio waves, heat waves, X-ray waves, gamma-ray waves, and the very short cosmic waves. The speed of electromagnetic waves is 300,000,000 meters per second, and the frequency is equal to the speed divided by the wave length. Hertz produced electric waves and measured their velocity on the basis of wave length and period of oscillation. Resonance of electric waves is created by sympathetic vibration, and an electrical circuit can be tuned by varying the capacitance and inductance.

The radio requires smooth and well-modulated oscillation at the microphone, sensitive detectors, and a means of amplifying the current at the receiving end. All these needs are met by the three-electrode tube, known as the audion tube. At the broadcasting station large audion tubes set up high-frequency continuous oscillatory currents which are modulated by voice currents. A carrier wave whose amplitude has been modulated by the audio frequency of the voice is broadcast. This modulation is called amplitude modulation. Frequency modulation, which is growing in use, does not change the amplitude of the carrier wave but varies the frequency of the oscillations by imposing on it the audio frequency of the voice. The receiving sets of today are tuned by variable condensers. The weak currents are amplified by audion tubes used as amplifiers. Audion tubes used as detectors change the radio-frequency currents into audio-frequency currents, which are amplified and converted to audible sounds by loud speakers.

SUMMARY

In television the picture of the scene must be dissected into hundreds of thousands of tiny points of light. Each point of light must be changed to electric impulses of high frequency. At the receiving end the electric impulses must be changed back to tiny points of light to form the picture. The iconoscope at the sending end dissects the picture and produces the electric impulses. The kinescope at the receiving end converts the electric impulses back into tiny points of light and combines these points into a replica of the original picture.

Cathode rays are streams of electrons produced by electrical discharges through tubes in which the pressure has been reduced to one-thousandth of a millimeter of mercury. X-rays are produced in cathode tubes when the cathode rays are caused to strike a tungsten or platinum disk. When electrons strike a body they set up very short waves known as X-rays. The X-ray radiations penetrate many substances that light waves do not penetrate. X-rays have great commercial and medical value.

In 1896 Becquerel discovered new rays given off by certain substances, such as uranium. Radium and other radioactive elements were first separated from uranium by Professor and Madame Curie. Radioactive substances are those substances whose atoms are disintegrating to atoms of lower atomic weight. Rutherford discovered that three kinds of radiations are emitted when atoms disintegrate. These radiations are called alpha, beta, and gamma. Alpha rays are streams of positively charged particles, consisting of two protons and two neutrons. Alpha particles become helium atoms when the needed electrons are acquired. The beta rays consist of negative electrons. The gamma rays are similar to X-rays but have much shorter wave lengths. The curative effects of radium are due to the gamma rays.

Artificial radioactive atoms are now produced by bombarding the nuclei of atoms by particles with a very high velocity. The cyclotron, devised by Professor Lawrence, splits up the nuclei of atoms by giving to protons and neutrons of hydrogen a very high velocity. From investigations made by the use of the cyclotron and the Wilson fog chamber, the nucleus of atoms is believed to

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be made up of protons, neutrons, and positrons. Neutrons have the same mass as the protons but have no electrical charge. The positron is the ultimate unit of electricity. Its mass is about the same as a negative electron.

Cosmic rays are a new form of radiation, coming to us out of space. Their exact nature has not been determined.

How do radio waves differ from the waves from a hot stove? from an electric lamp?

In what two ways can a radio be tuned? Which way is used in turning the dial of a radio?

Why is it possible to send short-wave radio great distances with small power in broadcasting stations?

Why is the custom of using high-frequency short waves for commercial broadcasting increasing?

What is meant by the radio direction finder of an airplane?

How does an airplane pilot fly a radio beam?

How can the intensity of X-rays produced in a Coolidge X-ray tube be increased? How can their penetrating power be increased?

What is the advantage of using a million or more volts in X-ray tubes for hospitals?

What are some of the common uses of photoelectric cells?

What other uses besides advertising are there for neon tubes?

What tubes, besides X-ray tubes, are modified cathode-ray tubes?

SOLVE THESE PROBLEMS

1. What is the frequency of oscillations of a radio wave of 300 meters length?
2. What is the wave length received when the radio is tuned to 1,500 kilocycles per second?
3. To what frequency is a short-wave set tuned when it is receiving 40-meter waves?

INVESTIGATIONS

1. If possible, visit a short-wave broadcasting station. Find out what supplies its power. How is the frequency regulated for the waves sent out? What stations in different parts of the world would this station hear and talk to?
2. Investigate the production and directing of radio beams used in aviation.
3. Visit some broadcasting station and observe the broadcasting equipment and methods.

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Glossary

The purpose of the following glossary is to aid students in gaining an understanding of technical terms used in this book. If any definition or explanation contains any term that is not understood, look up the meaning of that term in the glossary. Wherever a term listed is used in a special field only, that branch of learning is indicated usually in abbreviated form, thus:

Aero. for aeronautics

Elec. for electricity

Eng. for engineering

Math. for mathematics

Mech. for mechanics

Meteorol. for meteorology

Mus. for music

Radio is not abbreviated

To assist the student in the pronunciation of certain terms, phonetic spellings in parentheses follow the regular spellings.

KEY TO PRONUNCIATION

ā as in *ate*

â as in *vacation*

â as in *care*

ă as in *am*

ă as in *account*

ă as in *arm*

ă as in *ask*

ă as in *sofa*

ê as in *eve*

ê as in *event*

ě as in *end*

ě as in *silent*

ě as in *maker*

ī as in *ice*

ī as in *ill*

ĩ as in *possible*

ō as in *old*

ô as in *obey*

ô as in *lord*

ô as in *not*

õ as in *connect*

oo as in *food*

oo as in *foot*

ũ as in *cube*

ũ as in *unite*

ũ as in *urn*

ũ as in *up*

ũ as in *circus*

tũ as in *nature*

zh as in *azure*

Absolute altimeter (āl-tīm'ê-tēr): an instrument which measures the distance from an aircraft to the surface of the earth immediately beneath it, rather than the distance above sea level.

Absolute humidity: the amount of water vapor actually present in the air expressed in grains of weight per cubic foot of volume.

Absolute zero: the lowest possible temperature in the universe, or—273° C.

Absorption of radiant energy: the reception and transformation into heat of radiant energy which falls upon a surface.

Acceleration: the rate of change of velocity; the gain or loss of speed in a given unit of time.

Achromatic (āk'rô-măt'ik): without color; free from color.

Acoustics (ă-kōōs'tiks): the science of sound, including its production, transmission, and effects; the study of the effect of sound on the organs of hearing.

Adhesion: the molecular attraction which holds together the surfaces of bodies or substances in contact.

Aerial (ă-ě'ri-ăl): a wire or combination of wires used in radio broadcasting and wireless telegraphy for transmitting electric waves into space or receiving electric waves from space.

Aerial photography: the taking of photographs from an aircraft.

Aerodynamics (ă'ēr-ô-dī-năm'iks): a study of the forces which act upon an object, such as an airplane, as a result of the relative motion of the object and air.

GLOSSARY

Aeronautics (ā'ēr-ō-nō'tiks): the science that treats of the operation of aircraft; also, the art or science of operating aircraft.

Aeroplane (ā'ēr-ō-plān): an airplane.

Ailerons (ā'lēr-ōnz): small hinged wing flaps on an airplane, operated by the pilot to aid in controlling the horizontal balance.

Air: a colorless, odorless mixture of nitrogen, oxygen, and hydrogen, together with traces of other gases, water vapor, and impurities, all of which taken together is commonly known as the atmosphere.

Air brake: a brake operated by a piston driven by compressed air.

Air conditioning: the straining and movement of air and the regulation of its humidity and temperature.

Air mass: a large portion of the atmosphere which has similar characteristics with its properties such as temperature and moisture more or less uniform. Two classes of air masses are warm and cold masses.

Air pump: a pump used to draw air from a container to produce a partial vacuum; also a pump used to compress air.

Air speed: *Aero.*, the speed of an aircraft with relation to the air as distinguished from its speed with relation to the earth.

Aircraft: any form of machine for flying through the air.

Airfoil: *Aero.*, any flat or curved surface, such as an aileron, wing, elevator, or rudder, used to obtain reaction upon its surfaces from the air through which it moves.

Airplane: a flying machine propelled by motor and kept aloft with the aid of winglike planes.

Airship: any large aircraft supported by gas-filled bags and propelled through the air by mechanical power.

Alternating current: an electric current that reverses direction many times a second.

Alternator (āl'tēr-nā'tēr): an electric generator or dynamo for producing alternating currents.

Altimeter (āl-tim'ē-tēr): an instrument that registers atmospheric pressure used for measuring elevation above sea level.

Altitude: height above sea level.

Ammeter (ām'mē-tēr): an instrument for measuring the rate of flow of electric current.

Ampere (ām'pēr): the amount of electric current passing through a circuit, of which the resistance is one ohm under an electromotive force of one volt; the practical unit for measuring the strength of electric currents.

Amplifier (ām'plī-fī'ēr): a device which increases the magnitude of radio waves or sound waves.

Amplitude (ām'plī-tūd): the extent of displacement in a vibratory movement, as that of a pendulum, water wave, or sound wave.

Anemometer (ān'ē-mōm'ē-tēr): an instrument for measuring and recording the velocity of the wind.

Aneroid barometer (ān'ēr-oid bá-rōm'ē-tēr): an instrument consisting of a metallic box with a pressure gauge, levers, scale, and pointer, and used for measuring air pressure.

Angle of attack: *Aero.*, the angle between the chord of an airfoil and the direction of its motion relative to the air.

Angle of incidence: angle formed by an incoming ray of light and a line drawn perpendicular to the reflecting surface.

Angle of reflection: angle formed by a reflected ray of light and a line drawn perpendicular to the reflecting surface.

Anode (ān'ōd): the positive terminal or electrode of an electric apparatus at which the current enters.

Antenna (ān-tēn'ā): the long wire or wires used for sending out or receiving electromagnetic waves.

Anticyclone: a spiral movement of cool winds that blow outward from a high-pressure area.

Apparatus (āp'ā-rā'tūs): any machine, device, or set of utensils used to carry out an experiment or perform a special work.

Arc: a part of a curved line, such as a part of a circle or of an ellipse.

Archimedes' (ār'kī-mē'dēz) principle: the loss of weight, caused by the lifting force of a liquid on a body that floats or is submerged in it, is equal to the weight of the liquid displaced by the body.

GLOSSARY

- Armature** (är'má-tûr): a coil of wire wound around a soft iron core in which an electric current is developed.
- Artesian** (är-tē'zhăn) **well**: a well from which water flows spontaneously due to water pressure from a source beneath the earth's surface higher than the opening of the well.
- Aspirator** (äs'pī-rá'tēr): an apparatus for removing gas or liquids by suction.
- Astigmatism** (á-stīg'má-tizm): a defect of vision due to an irregular conformation of the cornea of the eye that causes horizontal and vertical lines to be seen with unequal clearness.
- Atmosphere** (ät'mös-fēr): the mass of air that surrounds the earth; one atmosphere is the pressure of air at sea level, used as a unit of measurement, equal to about 14.7 pounds per square inch.
- Atmospheric pressure**: the pressure exerted by the atmosphere not only downward but in all directions; pressure exerted on a body by the air, equal at sea level to about 14.7 pounds to the square inch.
- Atom**: the smallest part of an element that has all the chemical properties of the element.
- Attraction**: a force acting mutually between particles of matter tending to draw them together and resisting their separation; a force operating in a body and which tends to draw objects to it.
- Audio frequencies**: all vibrations which the ear can detect.
- Audion tube**: a three electrode electron tube.
- Aviation**: the art and science of flying by human beings, especially in airplanes.
- Avigation** (äv-i-gā'shûn): the science and art of navigating aircraft.
- Back electromotive force of a motor**: *Elec.*, the electromotive force generated by the armature of a motor due to its rotation in a magnetic field.
- Ballast** (bäl'ást): any heavy substance used to stabilize a balloon or ship.
- Balloon**: a bag of non-porous silk or other light fabric, filled with a gas lighter than air, that will rise up in the atmosphere.
- Bank**: *Aero.*, to incline an airplane laterally to prevent skidding when rounding a curve; the lateral inclination of an airplane, as when it rounds a curve.
- Banking**: the rolling of an airplane from a position with level wings into a position with one wing raised and the other one lowered.
- Bar**: *Meteorol.*, a unit of atmospheric pressure equal to that indicated by a mercury column with a barometric reading of 29.53 inches or 75 centimeters.
- Barograph** (bär'ô-gráf): a self-recording barometer that makes a continuous record of atmospheric pressure.
- Barometer** (bä-rôm'ê-tēr): an instrument for measuring atmospheric pressure.
- Barometric pressure**: atmospheric pressure measured by a barometer.
- Battery**: a group of cells connected for generating electricity.
- Beam**: *Aero.*, a radio beam, or repeated directional signals sent out from radio range stations for the guidance of pilots.
- Beat**: pulsation of sound caused by the periodic increase and decrease in loudness of sound due to alternate reinforcement and interference.
- Beat frequencies**: *Radio*, whenever electromagnetic waves of different frequencies are combined, a periodic reinforcement and cancellation occur.
- Beaufort** (bü'fêrt) **scale**: a scale devised for estimating wind velocity by noting the visible effects of the wind, indicated by numbers from 0 to 12; the corresponding terms are calm, light air, light breeze, gentle breeze, moderate breeze, fresh breeze, strong breeze, moderate gale, fresh gale, strong gale, whole gale, storm, hurricane.
- Bel**: a unit for measuring the relative loudness of two sounds; also, a unit for the logarithmic expression of ratios of voltage or current in wire or radio communication.
- Bernouilli's** (bër-nō-yēz') **principle**: the pressure of a fluid, such as air or water, decreases as the velocity increases, and increases as the velocity decreases.
- Biplane**: an airplane with two main supporting surfaces, one above the other.

GLOSSARY

Blade angle: *Aero.*, the angle that the chord of a blade element of an aircraft propeller blade makes with a plane perpendicular to the propeller of the aircraft.

Blade element: *Aero.*, a cross section of the blade of a propeller of an aircraft. Since the blades of a propeller are twisted, each cross section of the blade is different.

Block and tackle: a combination of fixed and movable pulleys, operated by means of a rope or chain, and used to lift heavy weights with comparatively small effort.

Boiling point: the temperature at which the vapor pressure is equal to the pressure upon the surface of the liquid.

Bonding an airplane: a feature in the structure of an airplane which consists of connecting all joints with low resistance conductors to prevent static discharges, which would cause interference in the radio system of the airplane.

Bourdon (bōōr-dōn') gauge: a pressure gauge used widely on air-pressure tanks and boilers of steam engines to show pressure by means of a pointer on a dial.

Boyle's law: if the temperature remains the same, the volume of a given weight of gas varies inversely to the pressure.

British thermal unit: the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit.

Brittleness: the property of matter, such as glass and chalk, that causes it to break easily.

Brownian movement: the rapid and irregular movement of tiny particles of a solid suspended in a liquid due to their bombardment by the surrounding molecules.

Bunsen burner: a burner in which the gas is mixed with air before reaching the place of combustion.

Buoyancy: the lifting force of fluids on floating or immersed bodies.

Burbling: *Aero.*, a disturbance of the free flow of air past an object by air from the nearest streamlines, which increases the resistance of the object to the relative wind.

Cable: *Elec.*, an insulated bundle of electric wires covered with water-proof material and used for a submarine telegraph line; also called submarine cable.

Caisson (kā'sōn): a large diving bell in the form of a water-tight compartment used to hold back water while construction work is being carried on inside and under water.

Calibrate (kāl'ī-brāt): to adjust an instrument or apparatus so that it will register accurately.

Calorie (kāl'ō-rī): the amount of heat required to raise the temperature of one gram of water one degree centigrade; a unit of heat in the metric system, also called small calorie. 1000 small calories equal a large calorie.

Cam: a device for changing circular motion into straight-line or back and forth motion, such as a disk on a rotating axis.

Camber (kām'bēr): *Aero.*, the rise of the curve of an airfoil section from its chord; the curvature of an airfoil.

Camshaft: a shaft with cams, such as is used in the gasoline engine to move valve rods.

Candle power: a unit for measuring lighting power, which is the amount of light produced by a sperm candle that burns 120 grains per hour.

Capacitance (kā-pās'ī-tāns): *Elec.*, that property of an isolated conductor or of a condenser which expresses its ability to keep the potential low for a given charge.

Capillarity (kāp'ī-lār'ī-tī): the action by which the surface of a liquid, when it is in contact with a solid, is elevated or depressed, as in a tube.

Capillary (kāp'ī-lēr-i) action: the force that causes liquids to rise and fill air spaces, as when water rises in the soil.

Capillary attraction: the force by which the surface of a liquid in raised where it touches the side of a container; the power of a porous substance, such as blotting paper, to draw up liquids.

Capstan (kāp'stān): a form of wheel and axle in which a drum or cylinder rotates around a vertical axis, used on ships for raising the anchor and hoisting other weights.

- Carburetor** (kär'bû-rêt'ër): a mechanism for converting liquid fuel in a gas engine into vapor and mixing it with the proper proportion of air to produce an explosion.
- Carrier wave:** the electromagnetic wave sent out by a radio transmitter.
- Cartesian** (kär-tē'zhăn) **diver:** a device used to illustrate certain principles that govern the pressure of fluids.
- Cathode** (kăth'öd): the negative terminal or negative electrode by which the electric current leaves.
- Ceiling:** the height above the ground to the bases of low clouds.
- Cell:** *Elec.*, a source of electric current which consists of two electrodes immersed in one or more electrolytes; sometimes called voltaic cell.
- Cells in parallel:** connections in which the negative electrodes of all cells are joined to one wire and the positive electrodes, to another.
- Cells in series:** connections in which the negative electrode of one cell is joined to the positive electrode of the next one.
- Center of gravity:** that point in a body from or on which it may be placed in equilibrium in any position.
- Center of pressure:** *Aero.*, a point on an airfoil at which a single force could replace all of the forces upon the airfoil and produce the same result.
- Centigrade** (sên'tî-grăd) **thermometer:** a thermometer on the scale of which the freezing point of water is 0° and the boiling point 100°, and the distance between is divided into 100 equal degrees.
- Centimeter** (sên'tî-mē'tēr): one hundredth of a meter, or .3937 of an inch.
- Centrifugal** (sên-trîf'û-găl) **force:** the pull on a body that moves in a curved path away from the center of curvature, and against the force that causes it to move in a curve.
- Centripetal** (sên-trîp'ê-tăl) **force:** the force that acts on a body which moves in a curved path and is directed toward the center of curvature and keeps the body from going off on a tangent.
- Charge:** *Elec.*, a potential given to a body by adding or taking away electrons, either by mechanical or chemical means.
- Charles's law:** if the pressure of a gas is constant, the volume is directly proportional to the absolute temperature.
- Choke coil:** *Elec.*, a reactor or a coil of small resistance and large inductance, used to impede or throttle an alternating-current circuit, or to change its phase.
- Chord:** *Aero.*, a line connecting the leading and trailing edges of an airfoil such as a wing or a blade of a propeller.
- Circuit:** *Elec.*, the complete path over which an electric current flows.
- Circuit breaker:** a device consisting of a switch that is opened automatically by an electromagnet and acts to interrupt an electric circuit in case of an overload.
- Circular mil:** the area of a cross section of wire one mil in diameter.
- Circumference:** the closed curve that bounds a circular area; the distance around a circular body.
- Clinical thermometer:** a self-registering thermometer used for measuring body temperature.
- Clinometer** (kli-nôm'ê-tēr): an instrument for measuring angles of slope, elevation, or inclination.
- Clutch of an automobile:** a friction device which connects the fly wheel to the transmission shaft.
- Cockpit:** *Aero.*, a space in the fuselage of an airplane occupied by the pilots.
- Coefficient** (kō'ê-fish'ênt) **of drag:** *Aero.*, the number of pounds of drag produced by a unit area of the wing when moving at a given angle through air one-half unit density and one unit velocity.
- Coefficient of expansion:** the ratio of increase in length, area, or volume of a body for a rise in temperature of one degree Centigrade to the original length, area, or volume.
- Coefficient of friction:** the ratio of parallel force required to cause an object to slide over a surface to the normal or perpendicular force pressing the two objects together.
- Coefficient of lift:** *Aero.*, at a given angle of attack, the number of pounds of lift produced by a unit area of the wing when it is moving in air with one-half unit density at unit air velocity.

GLOSSARY

- Coherer:** *Radio*, a detector in which an imperfectly conducting contact between conductors is improved in conductance by the passage of high-frequency current.
- Cohesion:** the force that holds molecules of the same kind together.
- Collimator** (kōl'i-mā'tēr): a tube having a convex lens at one end and at the other end a slit which is at the principal focus of the lens, used for producing a beam of parallel rays.
- Commutator** (kōm'ū-tā'tēr): a device consisting of an insulated copper ring, divided into pairs of segments, attached to the armature of a generator or dynamo and rotating with it, that changes alternating electric current into direct current.
- Compass:** an instrument that shows direction by means of a magnetized needle.
- Compass course:** in aviation, the course obtained by altering the magnetic course to allow for the deviation of the compass.
- Compass rose:** a graduated circle divided into 360° and placed on sectional and regional charts with both magnetic and true directions usually given. It is used by airplane pilots in plotting their course from place to place.
- Compensated pendulum:** a pendulum provided with a device for correcting variations in the length of the pendulum, such as the variations caused by a change of temperature.
- Complementary colors:** two contrasting colors which, mixed together in proper proportion, give a neutral color.
- Component of force:** effective part of a force in a given direction.
- Composition of forces:** finding a single force that will produce the same results as two or more forces.
- Compound bar:** a bar made by riveting or welding together two materials, such as iron and copper, that have different rates of expansion.
- Compressed air:** air of which the volume has been much reduced and that exerts a pressure greater than 15 pounds to the square inch.
- Compression pump:** a pump used to inflate or to increase the density and pressure of air in a container by increasing the amount of air.
- Concave:** curved inward as the inside of a hollow ball.
- Concave lens:** a lens having one or both sides concave, so that the middle is thinner than the edges.
- Condensation:** the bringing of particles closer together, as in reducing a gas to a liquid or a liquid to a solid; the process by which minute globules of water become visible as clouds.
- Condenser:** a device for accumulating an electric charge; a device for transforming gases or vapors into liquid or solid form; a chamber in a steam engine where the steam from the cylinder is condensed into water.
- Conduction:** the transmission of heat or electricity from one part of a body to another part, or from one body to another body in direct contact with it.
- Conductivity** (kōn'dūk-tīv'ī-tī): the property of a substance that enables it to transmit heat, light, or electricity.
- Conductor:** a substance that has the power of transmitting heat, electricity or sound.
- Conjugate foci:** any two points so related that light diverging from one converges to the other.
- Conservation of energy:** the existing amount of energy does not vary, but it may be converted from one form to another; energy cannot be created or destroyed, but its form may be changed.
- Conservation of matter:** the theory that matter can neither be created nor destroyed.
- Control stick:** *Aero.*, the vertical lever by which certain of the controls of an aircraft are operated.
- Control surfaces:** *Aero.*, the movable parts of the wings and tail of an airplane used to control elevation, direction, and stabilization.
- Controllable propeller:** *Aero.*, a propeller provided with blades of which the blade angle may be changed while the propeller is rotating in flight.
- Controls:** *Aero.*, the apparatus used to direct the altitude, direction of flight, power, and speed of aircraft.
- Convection** (kōn-vēk'shŭn): the process of transmitting heat by means of the movement of heated or electrified

- matter from one place to another, as by currents in a liquid or gas.
- Convex:** curved outward like the outside of a ball or globe.
- Convex lens:** a magnifying lens curved outward on one or both sides so that it is thicker in the middle than at the edges.
- Coolidge tube:** a tube for the generation of X-rays.
- Coulomb** (kōō-lōm'): the amount of electricity conveyed by one ampere in one second; a flow of 6,300,000,000,000,000,000 electrons.
- Crystalline lens:** a transparent body in the eye directly behind the pupil, which converges the light rays to a focus on the retina.
- Curvilinear** (kūr'vī-līn'ē-ār) **motion:** motion in a curved path, such as a body moving around a central point.
- Cycle:** the interval during which an alternating current of electricity flows backward and forward; also one series of operations by the pistons in the cylinder of a gas engine.
- Cyclone:** (sī'klōn): a storm caused by rotating winds that whirl counterclockwise in the Northern Hemisphere, inward toward a center of low barometric pressure.
- Cyclotron** (sī'klō-trōn): an apparatus designed to break down the unity of the atom.
- Cylinder** (sil'in-dēr): the chamber in an engine in which expanding steam or the explosion of a gas causes a piston to move.
- Damped oscillations:** oscillations which continually decrease in amplitude.
- Damped waves:** disconnected waves which decrease in amplitude until they fade out.
- Decibel** (dēs'ī-bēl): one-tenth of a bel, the usual unit for measuring the loudness of sound.
- Deflection:** the amount by which a pointer is displaced on the graduated scale of an instrument.
- Density:** the measure of mass per unit volume of a substance; or the relation of the weight of a substance to its volume.
- Detector:** a device used in radio which reveals the presence of wireless waves; a device for changing high-frequency electrical oscillations into direct current, such as the crystal detector and the vacuum tube detector.
- Dew:** moisture condensed upon the surfaces of cool bodies, especially at night
- Dew point:** the temperature of the air at which some of the vapor it contains is condensed and forms water.
- Dielectric** (dī'ē-lēk'trik): a nonconductor of electricity used between two conductors of electricity as used in condensers.
- Diesel** (dē'zēl) **engine:** an internal-combustion engine in which very high compression is used and no ignition system is required and which uses fuel oil as a source of power.
- Difference of potential:** a condition determining the tendency of an electric charge to move, or an electric current to flow, from one point to another, usually measured in volts.
- Differential:** an arrangement of gear wheels connecting two shafts in such a way that one of the two wheels may turn at a speed faster than the other.
- Diffusion:** the process by which fluids mix when poured together or when separated by a porous membrane.
- Diffusion of light:** the process of scattering light in all directions.
- Dihedral** (dī-hē'drāl) **wings:** *Aero.*, when the two wings of an airplane come together to form a small angle or a V shape.
- Diode** (dī'ōd): a vacuum tube that contains a cold electrode and a filament, used as a detector in a radio.
- Direct current:** electric current that flows constantly in one direction.
- Direct light:** light that falls directly from its source to the area where it is to be used.
- Direct proportion:** the increase in one quantity corresponds to an increase in the other.
- Direction finder:** *Aero.*, a device used in aviation to show the pilot the direction to set his course when not on the beam.
- Dirigible** (dīr'ī-jī-bl): a cigar-shaped airship, supported in the air by a gas lighter than air, and driven by motors.

GLOSSARY

Dissociation: the separation of compounds into ions.

Distillation: the process of driving off gas or vapor from liquids or solids by the application of heat and of condensing it by cooling.

Distributor: *Mech.*, a device in an internal-combustion engine which directs the high voltage secondary current of an induction coil to the various spark plugs in the proper firing order.

Drag: *Aero.*, a force that is parallel to the relative wind and acts in an opposite direction to thrust; the resistance caused by the wings and other surfaces of an aircraft.

Dry cell: *Elec.*, a voltaic cell sealed so as to prevent spilling of the electrolyte or in which it is made non-spillable by the use of an absorbent.

Dry ice: solid carbon dioxide, a substance with a temperature of -72°C . At a higher temperature dry ice changes into gas.

Ductibility: the property of a substance, such as copper or gold, which permits it to be drawn into a wire.

Ductile (dük'til): capable of being drawn out into wire, strands, or thread.

Dynamo (dī'nā-mō): a machine that converts mechanical energy into electrical energy by the induction of currents generated by the relative motions of conductors and magnetic fields; also, a machine that converts electrical energy into mechanical energy.

Dynamotor (dī'nā-mō'tēr): *Elec.*, a machine to change alternating current to direct current, or to change direct current to alternating current.

Dyne (dīn): a unit of force in the metric system equal to the force, which, acting on a gram for a second, gives it a velocity of a centimeter per second.

Eccentric (ĕk-sĕn'trik): off center; a circular disk set off center on a main shaft, so that the circular motion of the disk on its axis is changed to back and forth motion of the shaft.

Echo: the repetition of a sound caused by the reflection of its waves.

Eddy current: an induced electric current which circulates entirely within a mass of metal, and hence is a cause of waste.

Efficiency: the ratio of the useful work obtained from a machine, electric system, or the like, to the energy supplied to it to do work; the quality of producing the maximum effect with the minimum effort.

Effort: active or effective force exerted to do work.

Elastic limit: the point at which a substance, if stretched, fails to return to its original size and shape.

Elasticity (ĕ'lās-tis'ĭ-tī): that property of a substance that causes it to stretch and spring back to its original size and shape.

Electric cell: a device that develops electric energy by means of chemical action.

Electric current: the stream of electrons driven through a conductor.

Electric generator: a machine that changes mechanical energy into electrical energy.

Electric motor: a rotating machine that transforms electrical energy into mechanical energy.

Electric potential: the electric energy that a body possesses by virtue of the electric charge that it carries.

Electric tachometer (tā-kōm'ĕ-tēr): *Aero.*, an instrument which consists of a generator attached to the engine of an airplane, and which, by the voltage induced, indicates to the pilot the revolutions per minute of the engine.

Electric pressure: electromotive force.

Electrical resistance: the opposition a conductor offers to the passing of an electric current, causing heat.

Electricity: an invisible form of energy, capable under different circumstances of producing light, heat, power, chemical decomposition, and other physical phenomena, and which gives certain metals the power to pull together or to push apart.

Electrodes (ĕ-lĕk'trōds): the carbon or copper and zinc strips or plates used in an electric cell; either of the conductors by which an electric current enters and leaves the electrolyte. *See* Anode and Cathode.

Electrolysis (ē'lēk-trōl'ī-sīs): the decomposition of a chemical compound by means of an electric current.

Electrolyte (ē-lēk'trō-līt'): a substance that conducts electricity when in a water solution; the liquid used in an electric cell, which attacks one of the plates chemically.

Electromagnet: an artificial temporary magnet, made by winding insulated copper wire closely around a bar of soft iron, and connecting the ends of the wires to the terminals of an electric battery.

Electromagnetic (ē-lēk'trō-māg-nēt'īk) **induction:** the production of an electric current by a relative motion of a conductor in a magnetic field.

Electromagnetic wave: a wave produced by the oscillation of an electric charge.

Electromagnetic waves: electromagnetic fields set up around a wire which carries an alternating current of electricity.

Electromotive force: electric pressure in a conductor.

Electron: a very minute negatively electrified particle charged with the smallest known quantity of electricity; a component part of the atom charged with negative electricity and complementary to the proton.

Electron tube: a vacuum tube which consists of a heated cathode, of an anode, or plate, and of a third electrode, or grid, for controlling the current flowing between the other two electrodes, all contained in a tube evacuated to a very low pressure.

Electrophorus: (ē-lēk-trōf'ō-rūs): a simple apparatus for generating static electricity by induction, consisting of a plate of metal and a disk of resin, shellac, ebonite, or rubber.

Electroscope: an instrument for detecting the presence of electricity.

Elevator: *Aero.*, a movable plane device attached to the end of the stabilizer for controlling the altitude or inclination of an airplane by inclining it up and down like a horizontal rudder.

Energy: the capacity for doing work, that is, for putting matter in motion, for retarding matter in motion, or changing the direction of matter in motion.

Equilibrium (ē'kwī-lib'rī-ūm): the state of balance between opposing forces.

Erg: the smallest unit of energy or work in the centimeter-gram-second system of units; 13,560,000 ergs are equal to one foot-pound.

Evaporation: the conversion of a liquid or solid into vapor.

Expand: to become larger and occupy more space.

Expansion: the increase in size, extent, or volume, as that caused by heat acting on a substance.

Experiment: a trial or operation to discover something not known previously, or to confirm or disprove something, or to find out what will result.

Factor of safety: the ratio of the ultimate strength of a piece of material to the actual working stress when in use.

Fairing: *Aero.*, a feature in the structure of an airplane designed to produce a smooth outline and to reduce drag or resistance.

Farad (fār'ād): unit for measuring the capacity of a condenser; if a condenser is charged with one coulomb of electricity and exerts a pressure of one volt, the capacity of the condenser is one farad.

Fahrenheit (fā'rēn-hīt) **thermometer:** a thermometer on the scale of which the freezing point of water is 32° and the boiling point 212°.

Farsightedness: a defect of vision due to the forming of images behind the retina and which is corrected by the use of convex lenses.

Fathometer (fā-thōm'ē-tēr): a device for measuring ocean depths by means of the rate of speed of sound in water.

Field coil: the wire wound in a spiral used in generators and motors to produce the magnetic field.

Filament (fīl'ā-mēnt): the carbon or metallic threadlike conductor in an electric light bulb or in a radio electron tube, which is made to glow with intense heat by the passage of an electric current.

Fin: *Aero.*, a small vertical plane projection on an airplane used in stabilizing and balancing the aircraft.

GLOSSARY

Fireless cooker: an insulated chest in which foods raised to the cooking temperature may be kept hot and cooking, by a heated disk, without further application of outside heat, until completely cooked.

Flexible: easily bent without breaking.

Fluid: a form of matter, such as water and air, that moves easily and changes its form and relative position without a separation of the mass.

Fluorescence (flōō'ô-rēs'ěns): the property of some substances of becoming luminous or of emitting light while exposed to the action of certain rays.

Fluoroscope (flōō'ô-rô-skôp): an instrument consisting of a screen with a hood used to observe shadows cast by objects in the path of X-rays and employed to make diagnoses.

Flying boat: a seaplane of which the hull serves both as a fuselage and landing gear.

Focal length or distance: the distance between the center of a lens and the principal focus.

Focus: a point at which rays of light, heat, or sound converge, or from which they appear to diverge after they are reflected or refracted; to bring light rays together at a central point.

Fog: a cloud near the surface of the earth.

Foot-candle: the illumination produced by a light of one candle power upon a surface one foot away.

Foot-pound: the amount of work required to lift one pound of matter a vertical distance of one foot.

Foot-poundal: a unit of work equal to the work done when a poundal of force moves one foot.

Force: any cause that produces, stops, changes, or tends to produce, stop, or change the motion of a body.

Force arm: that part of a lever to which the force or effort is applied.

Force pump: a pump having a solid piston for drawing and forcing a liquid through the valves to raise it to a considerable height above the pump, often with the aid of air pressure from an attached air dome. City fire departments use force pumps to put out fires in high buildings.

Four-cycle engine: an internal-combustion engine in which four strokes of the piston are required to complete one series of operations within the cylinder, namely, the suction stroke, the compression stroke, the power stroke, and the exhaust stroke.

Freezing point: the temperature at which a liquid begins to be transformed into a solid state; for water, 32° Fahrenheit; 0° Centigrade.

Frequency: the number of regularly recurring vibrations or cycles that take place in a given unit of time.

Frequency modulation: the impressing on a carrier wave the variations of frequency set up by the voice of the speaker or the variation in pitch in music.

Friction: resistance to relative motion of two or more surfaces in contact with one another.

Front: *Meteorol.*, the boundary between different air masses.

Frost: condensation of water vapor into minute ice crystals on or near the ground when it has cooled to 32° F.

Fulcrum (fŭl'krŭm): the support or pivot point on which a lever turns.

Fundamental: of basic, essential, or primary importance.

Fundamental tone: the lowest tone produced when the string of a musical instrument vibrates as a whole.

Fuse: a safety device in a conductor made of metal having a low melting point, and which is used to break an electric current when it becomes dangerously strong.

Fuselage (fŭ'zě-lij): the elongated body of an airplane, to which are attached the wings, rudder, and landing gear.

Galvanometer (găl'vá-nŏm'ě-tēr): an instrument for detecting the existence, determining the direction of flow, and measuring the intensity of an electric current, by the movement of a coil between the poles of a permanent magnet.

Gas: an elastic, airlike fluid, that tends to expand indefinitely and to occupy the total volume of any container.

Gas engine: an internal-combustion engine in which the piston is driven by the explosion of a mixture of gas and air.

Gas meter: an instrument used for measuring and recording the number of cubic feet of gas consumed.

Gasoline: a liquid distilled from petroleum, highly volatile and inflammable, and capable of evaporation, used principally as a source of power in internal-combustion engines.

Gasoline engine: an internal-combustion engine in which gasoline is used as the source of power.

Gauge (gāj): any device for measuring or recording, such as those used for measuring rainfall, wind velocity, steam pressure, amount of water in a boiler, and thickness of wire.

Gear wheels: wheels with edged teeth or cogs, mounted on different axles, with the cogs of one wheel fitted into the cogs of another so that, when one wheel turns, it causes the other wheel to turn also.

Geissler (gis'lēr): tubes: *Elec.*, glass tubes in which the air has been replaced by a gas at low pressure, and which become luminous when an electrical discharge is sent through them.

Generator: any machine used for changing mechanical energy into electrical energy; an apparatus for producing gas, steam, or electricity.

Glider: *Aero.*, an aircraft similar to an airplane which depends on air currents and not on any engine for its support and motive power.

Governor: *Mech.*, an automatic mechanical device for regulating the speed of an engine by controlling the flow of steam into the cylinder.

Grade: the measure of the steepness of ascent of an incline per unit of horizontal distance, measured in per cent; important in road construction.

Gram: the principal unit of weight in the metric system, equal to the mass of one cubic centimeter of distilled water at maximum density; it is equal to 15.432356 grains.

Gram calorie: the amount of heat required to raise the temperature of one gram of water one degree Centigrade.

Gram-centimeter: a unit of work equal to the work done in raising a weight of one gram through a vertical distance of one centimeter.

Gram of force: a force that will cause 980 grams of mass to accelerate one centimeter per second each second.

Gravitation (grāv'i-tā'shŭn): the force which draws all bodies in the universe toward one another.

Gravity: the force that draws all bodies toward the center of the earth and thus gives them weight.

Grid: *Elec.*, an electrode placed between the filament and the plate of a radio tube to control the electric current between plate and filament; also a zinc plate in a primary battery or a lead plate in a storage battery.

Grid bias potential: a negative potential used in detector tubes to separate the radio frequency carrier current from the audio-frequency pulsating current which can be changed to sound waves by the loud speaker.

Grid circuit: *Elec.*, the electric circuit which includes the grid and the hot electric filament (cathode) of an electron tube.

Grid condenser: *Elec.*, a condenser connected in series in the grid circuit of an electron tube.

Grid current: *Elec.*, a current flowing between the grid and the cathode of an electron tube.

Gyro-directional compass: a compass that indicates directions due to the stability of a gyroscope.

Gyroscope (jī'rō-skōp): an instrument which is given stability due to the centrifugal force of a rapidly rotating heavy wheel, so mounted that it is free to rotate about any axis.

Hail: frozen rain falling in the form of little pellets.

Hardness: the property of any solid which causes it to resist impression by an outside force and that enables it to make impressions on other substances.

Harmonic: *Mus.*, a note of which the vibration rate is a whole number multiple of that of the fundamental; an overtone.

Heat: a form of energy produced by the sun, combustion, chemical action, friction, and electric current, resulting in increased temperature, and due to very rapid movement of molecules.

GLOSSARY

Heat equivalent of electrical energy: the amount of heat produced by the expenditure of one unit or joule of electrical energy.

Heat of fusion: the amount of heat required to melt one gram of solid without changing its temperature; for ice it is 80 calories.

Heat of vaporization: the amount of heat required to change one gram of a substance from liquid to vapor without change of temperature, that is, at 212° F. or 100° C.

Helicopter (hě'l'i-kōp'tēr): a form of aircraft the support of which in the air is derived from the reaction of a stream of air driven downwards by propellers that revolve around a vertical axis.

Heliograph (hě'l'i-ō-gráf): an apparatus for telegraphing by means of reflecting rays of sunlight from a mirror.

Helium (hě'l'i-ūm): a very light, colorless, noninflammable gas, used for inflating balloons and dirigibles.

Henry: *Elec.*, the unit of inductance; the inductance of a circuit in which an electromotive force of one volt is induced by a current varying at a rate of one ampere per second.

Hertzian waves: electromagnetic waves first studied systematically by Hertz.

Heterodyne (hět'ēr-ō-dīn') **reception:** *Radio*, reception produced by the oscillation set up by another tube in the circuit.

High-pressure area: area of the atmosphere with a high barometric pressure, indicating fair weather.

Hooke's law: within the elastic limit of a substance, the strain is proportional to the stress that produces it.

Horse power: a unit of work equal to 550 foot-pounds per second.

Hull: *Aero.*, the body of a seaplane which corresponds to the fuselage in a land airplane.

Humidity: the water vapor in the air.

Hurricane (hūr'i-kān): a violent cyclonic whirlwind, originating over the ocean, common in tropical countries, and covering large areas.

Hydraulic (hī-drōl'ik): pertaining to the science that deals with water or other liquids in motion.

Hydraulic brake: a brake operated by a piston driven by a liquid.

Hydraulic jack: a device designed for lifting or raising heavy weights by applying great force to a large plunger or piston by means of water forced into the cylinder in which it moves.

Hydraulic lift: an elevator operated by the pressure of water.

Hydraulic press: a machine in which great force is applied with slow motion to a large plunger by means of water forced into the cylinder in which it moves.

Hydroairplane: an airplane provided with pontoons instead of wheels, so that it can travel on water and arise from and alight on it.

Hydroelectric (hī'drō-ē-lēk'trik) **power:** electric energy generated by the use of water power.

Hydrometer (hī-drōm'ē-tēr): an apparatus consisting of a closed, graduated tube, loaded so as to float upright and used for determining the specific gravity of liquids.

Hydroplane (hī'drō-plān): a diving rudder used on submarines; a flat-bottomed type of motor boat of very light construction of which the front part is raised above the water at high speed.

Hygrodeik (hī'grō-dīk): an instrument for measuring relative humidity, absolute humidity, and dew point.

Hygrometer (hī-grōm'ē-tēr): an apparatus for measuring the degree of moisture of the atmosphere; an apparatus for finding the relative humidity of the air.

Iconoscope: a dipper-shaped evacuated camera tube used in television to transform a picture into a succession of electric impulses to be sent to the receiving station.

Ignition system: the parts of a gas engine which bring about the explosion of the charge in the cylinders.

Image: the optical counterpart of an object produced by a lens, mirror, or other optical system.

Impedance (īm-pē'dāns): *Elec.*, the total opposition, measured in ohms, offered to an alternating current in a circuit. Impedance is found by combining the reactance and the resistance.

- Impulse:** force multiplied by the length of time it acts.
- Incandescence** (in-kăn-dēs'ěns): the giving off of light as a result of intense heat.
- Incandescent** (in-kăn-dēs'ěnt): glowing white or luminous with intense heat.
- Incandescent lamp:** a glass bulb in which a thin filament gives off light when charged with an electric current.
- Inclined plane:** one of the so-called simple machines consisting of a sloping surface that forms an acute angle with a horizontal plane and is used to raise heavy weights easily.
- Indirect light:** lighting where the rays are reflected from the ceiling or other opaque surface external to the fixture, to the place where the light is used.
- Induced current:** an electric current produced when a magnet is moved within a coil of insulated wire, or when a coil is rotated within or moved across the field of a magnet.
- Induced magnetism:** magnetism that is created temporarily in a piece of iron when it comes into contact with or is brought near a magnet.
- Inductance:** the inertia of the current of electricity which causes it to oppose any change in rate or direction of its flow by inducing an opposing electromotive force. Inductance is measured in henries.
- Induction:** an electric or magnetic condition produced in a body when placed in an electric or magnetic field.
- Induction coil:** an electrical apparatus consisting of concentric coils of very fine wire insulated from each other, so shaped that a strong iron bar magnet may be thrust in and out, used for the production of induced current of high potential.
- Induction motor:** a motor in which a rotating field is set up in the stator which induces currents in the rotor and causes it to rotate.
- Inertia:** that property of matter which causes a body at rest to tend to remain at rest, and which causes a body in motion to tend to remain in motion at the same rate and in the same direction until acted on by an outside force.
- Instrument:** a mechanical device; *Mus.*, a mechanical contrivance for producing musical sounds.
- Insulation** (in-sū-lā'shŭn): the act of separating by nonconducting materials; the state of being separated by nonconductors to prevent the passage of electricity, heat, or sound.
- Insulator** (in'sū-lā'tēr): a material that prevents the passage of electricity, heat, or sound; a nonconductor.
- Intensity:** the degree or amount of a condition, quality or physical attribute, as of light, sound, or electric current.
- Intensity of electric current:** the rate of flow of electrons; the number of electrons that pass a given point in one second, measured in amperes.
- Intensity of light:** brightness or brilliancy of light.
- Intensity of sound:** loudness of sound.
- Interference of light waves:** the destruction or neutralization of light waves by their getting out of step or phase, resulting in black lines.
- Internal-combustion engine:** an engine in which power is generated within a cylinder or cylinders, by an explosion of a mixture of air and a liquid fuel, such as gasoline in automobile engines, kerosene in farm tractor engines, and fuel oil in Diesel engines.
- Intervalometer** (in'tēr-vā-lŏm'ē-tēr): a timing device used in aerial photography to indicate the intervals between exposures as determined by ground speed and altitude of the aircraft.
- Inverse proportion:** the increase in one quantity corresponds to a decrease in the other.
- Ion** (i'ŏn): one of the minute particles that bear electrical charges which transmit electric current through the air or other gases.
- Ionization** (i'ŏn-i-zā'shŭn): the process by which particles of gas become converted into carriers of electricity.
- Ionosphere** (i-ŏ'nŏ-sfēr): the upper part of the atmosphere from about 60 miles above the earth's surface and extending up about 500 miles.
- Isallobar** (i-sāl'ŏ-bār): *Meteorol.*, a line on a chart connecting the places of equal change of atmospheric pressure within a given time.

GLOSSARY

Isobars (i'sô-bärz): on a weather map, the lines that connect places on the earth's surface having the same barometric pressure.

Isogonic (i'sô-gôn'ik) **lines**: lines on a map that join places on the earth's surface where the magnetic declination, or deviation from true north, is the same.

Isotherms (i'sô-thûrmz): on a weather map, the lines that connect places on the earth's surface having the same temperature at a given time, or the same mean temperature for a given period.

Joule (jōol): a unit of energy or work, the practical equivalent of the energy expended in one second by an electric current of one ampere in a resistance of one ohm, equal approximately to .738 of a foot-pound or 10,000,000 ergs; a watt-second, equal to one watt per second.

Kilocycle: one thousand cycles; *Radio*, one thousand cycles per second.

Kilogram (kîl'ô-grām): a unit of weight of the metric system, equal to 1,000 grams, or 2.2046 pounds.

Kilogram calorie: the amount of heat required to raise the temperature of 1,000 grams of water one degree C.

Kilogram-meter: a unit of work equal to the energy expended in raising a weight of one kilogram through a perpendicular distance of one meter; nearly $7\frac{1}{4}$ foot-pounds.

Kilometer (kîl'ô-mē'tēr): a unit of length of the metric system, equal to 1,000 meters, 3,280.8 feet, or .62137 of a statute mile.

Kilowatt (kîl'ô-wōt): a unit for measuring large quantities of electricity, equal to 1,000 watts.

Kilowatt-hour: a unit of work equal to that done by a kilowatt acting for one hour.

Kinescope: a large funnel-shaped vacuum tube used in television at the receiving station to convert the electric impulses coming from the iconoscope into the image of the view originally scanned.

Kinetic energy: the capacity for doing work that an object possesses because it is in motion.

Lactometer (lāk-tôm'ê-tēr): an instrument for determining the specific gravity of milk to ascertain if water has been added to it.

Landing gear: the understructure of an aircraft, including wheels or pontoons, used to carry the load when in contact with land or water.

Latent heat: heat that does not reveal its presence by causing a change in temperature.

Lateral axis: *Aero.*, a line through the center of gravity crosswise of the plane, which in level flight is horizontal.

Law of Charles: when the pressure is kept constant, the volume of a given mass of gas increases for a given rise of temperature, or decreases for a given fall, by a definite fraction of its volume.

Law of conservation of energy: energy cannot be created nor destroyed but only transformed and directed.

Law of electrical charges: like electrical charges repel each other; unlike electrical charges attract each other.

Law of magnetic poles: like poles of a magnet repel each other; unlike poles of a magnet attract each other.

Law of magnetism: unlike magnetic poles attract each other; like magnetic poles repel each other.

Law of reflection: the angle of incidence equals the angle of reflection and lies in the same plane.

Laws of electrical resistance: (a) The resistance of a conductor is directly proportional to its length. (b) The resistance of conductors varies inversely as the areas of their cross sections. (c) Materials of the same size do not have the same resistance. (d) A change of temperature produces varying changes in different materials.

Leading edge: *Aero.*, the forward portion of an airfoil, such as the forward portion of a wing or propeller blade.

Lens (lěnz): a transparent or refracting piece of glass or other substance with two opposite regular surfaces, of which at least one is curved; also the crystalline lens of the eye.

Lever: a bar capable of turning on a fixed point and upon which effort may be applied to overcome resistance.

GLOSSARY

- Leyden (lî'děn) jar:** a form of condenser for static electricity, consisting of a glass jar coated on the inside and outside, almost to the top, with tin foil and provided with a metallic knob and rod, mounted in an insulating cover.
- Lift:** *Aero.*, a force on the wing that helps support an airplane in flight and which always is perpendicular to the relative wind.
- Lift pump:** a pump that lifts and discharges liquids, which consists of a cylinder, an inlet valve, a piston with a valve, a handle to work the piston, and which operates with the aid of air pressure.
- Light:** a form of radiant energy received from the sun or other source and which is capable of acting on the normal eye in such a way as to make visible objects from which it comes.
- Lightning:** the discharge of atmospheric electricity between clouds that carry unlike electric charges, or between a cloud and an oppositely charged object on the earth's surface; the flash of light caused by the electrical charge.
- Lightning arrester:** a device for protecting electrical instruments from lightning by deflecting the discharge to the ground.
- Lightning rod:** a metallic conductor which extends in a sharp point above a structure and down to water or wet earth, designed to attract the electrical discharge and lead it to the ground.
- Light-year:** the distance that light travels in one year at the rate of 186,000 miles per second.
- Lines of magnetic force:** lines marking at all their points the direction in which magnetic force is acting.
- Liquid:** a form of matter in an inelastic fluid state in which the molecules move freely among themselves, and which remains in one mass, keeps the same volume, and takes on the form of the container.
- Liquid pressure:** the force exerted against a unit area of the container.
- Liter (lê'tēr):** the standard metric unit of capacity, 1,000 cubic centimeters, equal to .908 of the U. S. dry quart and 1.0567 U. S. liquid quarts.
- Local action:** the wasting of zinc and of energy in an electric cell, due to particles of impurities that cause small local circuits to be set up.
- Lodestone (lôd'stôn):** a natural magnet; magnetic oxide of iron that has the property of attracting iron and steel.
- Longeron (lôn'zhă-rôn'): a long longitudinal member of the frame of the fuselage of an airplane, continuous across a number of points of support.**
- Loop antenna:** *Aero.*, a radio receiving and transmitting device with directional properties used on airplanes in connection with direction finders and for radio beam work.
- Loud speaker:** the device in a radio which increases the sound when electric currents are converted into sound waves.
- Low-pressure area:** area of the atmosphere with a low barometric pressure, indicating storm centers.
- Lumen:** the amount of light transmitted by a lamp of one candle power to one square foot of surface at a distance of one foot.
- Machine:** a device that serves to apply, modify, and transform force and motion so as to do work, or to produce another result.
- Magdeburg hemispheres:** two hemispherical cups, which, when placed face to face, form a cavity from which most of the air can be withdrawn with a vacuum pump, and which are used to demonstrate air pressure.
- Magnet:** a body, such as a stone or piece of iron or steel, that possesses the property of attracting iron and steel.
- Magnetic declination:** the angle which the magnetic needle forms with the geographical meridian.
- Magnetic deviations:** errors in the indications of a magnetic compass caused by the presence of iron near the compass.
- Magnetic field:** the space near a magnet or an electric current where magnetic force is exerted and in which the magnetic needle will take a fixed position.
- Magnetic flux:** the total inductive effect exerted through a given area by a magnetic field.

GLOSSARY

- Magnetic inclination:** the angle formed with the horizon, or with a horizontal line, by a magnetic needle free to move vertically in a plane of the magnetic meridian; the angle of the dip of the magnetic needle.
- Magnetic needle:** a magnetic steel bar, mounted so as to permit it to turn freely, as in a compass.
- Magnetic pole:** one of the ends of a magnet.
- Magnetic tachometer** (tá-kǒm'ê-tēr): *Aero.*, an instrument which indicates the revolutions per minute of an air-plane engine, using a rotating magnetic field set up by rotating magnets, and a disk rotor in which eddy currents tend to cause it to rotate.
- Magnetic variation:** the angle between the true north and the direction indicated by the north-seeking pole of a magnetic compass.
- Magnetism:** the form of energy possessed by a magnet of attracting such substances as iron and steel.
- Magnetite** (mǎg'ně-tit): oxide of iron that has the property of attracting iron and steel; a lodestone.
- Magneto** (mǎg-ně'tō): a small dynamo that generates the current for the ignition in certain internal-combustion engines and that is driven by the engine itself.
- Malleability:** the property of matter, such as iron, gold, or copper, that permits it to be hammered or rolled into sheets without breaking or cracking.
- Manometer** (má-nǒm'ê-tēr): an instrument used for measuring the pressure of gases and vapors.
- Mass:** the quantity of matter in a body measured by its resistance to change of motion.
- Matter:** anything, such as a solid, a liquid, or a gas, that occupies space and has weight.
- Measurement:** the determining of the extent, dimensions, quantity, or capacity of matter by means of a standard.
- Mechanical** (mê-kǎn'î-kǎl) **advantage:** the ratio between the force exerted by a machine and the effort applied to it; ratio of effort to resistance.
- Mechanical energy:** the energy of motion, often called kinetic energy.
- Mechanical equivalent of heat:** the mechanical energy expended to raise the temperature of a unit weight of water one degree.
- Medium:** an intervening substance, such as air or water.
- Megaphone** (mĕg'â-fōn): a device to magnify sound and to direct it in greater volume.
- Meniscus** (mĕ-nīs'kūs): a crescent-shaped surface, as applied to lenses for the eyes and to the surface of the top of mercury in a capillary tube.
- Mercury** (mŭr'kŭ-rĭ): a heavy silvery metallic element that is liquid at ordinary temperatures; also called quicksilver.
- Mercury barometer** (bâ-rǒm'ê-tēr): an instrument that includes a column of mercury in a glass tube used for measuring air pressure.
- Meteorology** (mĕ'tĕ-ōr-ōl'ō-jĭ): the science that treats of the atmosphere and its phenomena, including the observing and recording of atmospheric conditions from which weather predictions are made.
- Meter** (mĕ'tēr): the standard unit of length in the metric system, equal to 39.37 inches; also, a device or instrument for measuring, usually for indicating and recording the quantity measured, as gas meter, water meter, and electricity meter.
- Metric system:** a system of measurement in which the units increase or decrease from the standard unit in a decimal scale.
- Metronome** (mĕ'trō-nōm): an instrument consisting of an inverted pendulum, moved by clockwork, with a weight adjustable to various rates of speed, used for marking off exact intervals of time, especially in music.
- Micrometer** (mĭ-krǒm'ê-tēr): an instrument for measuring minute distances.
- Micrometer caliper:** a gauge with a very fine screw for making very accurate measurements of thickness.
- Microphone:** the part of radio equipment which converts sound waves into electric currents for transmission.
- Microscope:** an optical instrument that magnifies minute objects greatly by means of a combination of lenses, so that they may be seen and studied.

Mil: a unit of length equal to one one-thousandth of an inch, used for measuring the diameter of wires.

Mil-foot of wire: a wire one foot long and with a cross section of one circular mil.

Milliammeter (mīl'ī-ām'mē'tēr): an instrument for measuring thousandths of amperes.

Millibar: *Meteorol.*, a unit of atmospheric pressure equal to one one-thousandth of a bar.

Millimeter (mīl'ī-mē'tēr): the thousandth part of a meter, or .03937 of an inch.

Mirage (mē-rāzh'): an optical illusion, occurring on oceans, deserts, and plains, caused by refractive conditions due to difference in temperature between the upper and lower strata of air near the earth's surface.

Modulate: to vary the amplitude or frequency of an electromagnetic wave.

Molecule: the smallest group of atoms in matter that retain the characteristics of a substance.

Moment: *Phys.*, the tendency, or the measure of the tendency, to produce motion, especially about an axis or point.

Momentum (mō-mēn'tūm): the quantity of motion in a moving body as measured by the product of its mass and velocity.

Monochromatic (mōn'ō-krō-māt'ik) **light:** light of a single wave length, and hence of one color.

Monocoque (mō-nō-kōk') **fuselage:** *Aero.*, a type of fuselage in which reliance is placed on the strength of its shell or veneer to carry the stresses arising in the fuselage.

Monoplane: an airplane that has but one main supporting surface.

Morse Code: the telegraphic alphabet consisting of dots, dashes, and spaces, invented by Samuel F. B. Morse.

Motion: the relative change of position between two bodies.

Motion picture: a series of instantaneous photographs taken at such brief successive intervals as to reproduce the continuous action of the things or scenes pictured when projected on a screen.

Motor: a machine that changes into mechanical energy some other form of energy.

Muffler: a device for deadening noise.

Multipolar generator: a generator which has more than two poles.

Music: sounds having rhythm, melody, or consonance, whether vocal or instrumental; harmonious combination of tones.

Nature: the universe, including all natural beings, forces, and processes.

Nearsightedness: a defect of vision caused when the lenses of the eyes form images in front of the retina; seeing distinctly at very short distances only. This defect is remedied by concave lenses.

Negative charge: the kind of electricity produced by rubbing resin with flannel.

Negative electricity: electricity of which the elementary unit is the electron.

Neon (nē'ōn): a colorless, odorless gas found in the atmosphere of which it constitutes a very small fraction of one per cent.

Neon lamp: a gas-discharge lamp in which the discharge takes place through a mixture of gases that contain a large proportion of neon.

Neutral: any object that shows neither a positive nor a negative electric charge; neither positive nor negative.

Neutral equilibrium: the equilibrium of a body when the center of gravity remains at the same level if the body is moved slightly, as a perfect sphere or cylinder.

Neutron (nū'trōn): a component part of the atom that has neither a positive nor a negative charge of electricity.

Newton's laws of motion: (a) Inertia: A body at rest remains at rest and a body in motion remains in motion in a straight line with undiminished speed, unless acted upon by an external force. (b) Acceleration: Every force acting upon a body changes the velocity of the body by an amount proportional to the magnitude of the force and to the time it acts. (c) Reaction: for every action there is an equal and opposite reaction.

Node: a point, line, or surface of a vibrating body marked by relative freedom of vibratory motion,

GLOSSARY

- Noise:** the sound that results from discordant vibrations.
- Normal:** *Math.*, a line drawn perpendicularly to the surface.
- Normal air pressure:** the amount of air pressure at sea level, or 14.7 pounds per square inch.
- Normal axis:** a vertical line through the center of gravity of an airplane when it is in level flight.
- Null position of a loop:** *Aero.*, the position when the plane of the loop is at right angles to the transmitting station and the signal practically disappears; used in direction finders.
- Objective lens:** the lens of a telescope or a microscope that is nearest to the object that is being viewed. It always produces a real image of the object.
- Ohm** (ôm): the unit for measuring resistance to the flow of electricity equal to the resistance offered by a conductor when one ampere flows under a pressure of one volt.
- Ohm's law:** the intensity of an electric current in a circuit equals the electromotive force divided by the resistance, that is, the amperes equal the volts divided by the ohms.
- Opaque** (ô-pāk'): impervious to the rays of light; the opposite of transparent; not permitting passage to the rays of light.
- Optical illusion:** perception of an appearance that does not correspond to the real thing.
- Oscillation** (ôs'î-lā'shŭn): backward and forward motion, as that of a pendulum.
- Oscillator** (ôs'î-lā'tēr): *Elec.*, a device for changing the direct current from a battery into an alternating current; any device for producing electrical oscillations; *Radio*, a radio-frequency generator of the nonrotating type.
- Osmosis** (ôs-mô'sis): the process by which liquids and dissolved materials pass through a thin membrane.
- Overtone:** a tone produced by a sound-producing object, such as a piano wire, vibrating by parts.
- Parachute:** an umbrella-shaped device used as a means of descent from an aircraft.
- Parallel connection:** a joining of two or more electric cells by connecting the positive poles to one wire and the negative poles to another.
- Partial vacuum** (vāk'û-ŭm): a space from which part of the air has been removed; a space in which air pressure has been decreased.
- Pascal's** (päs-kälz'): **law:** pressure exerted anywhere on a confined liquid is transmitted undiminished throughout the interior of the containing vessel; a fluid transmits pressure equally in all directions.
- Pendulum** (pĕn'dŭ-lŭm): a body suspended from a fixed point so that it is free to swing back and forth.
- Pentode:** a five-element vacuum tube.
- Penumbra** (pĕ-nŭm'brā): the partially lighted part of a shadow.
- Period:** the interval of time required for a recurring motion or phenomenon to complete a cycle and to begin to repeat itself, as the period of an alternating current of electricity.
- Periscope** (pĕr'î-skōp): an optical instrument consisting of a projecting tube equipped with a system of lenses and reflectors, either mirrors or prisms, which transmit scenes and objects, usually on the surface of the sea, to an observer below.
- Permalloy** (pŭrm'ă-loi'): an alloy composed of 80% nickel and 20% iron, very easily magnetized, and used for submarine telegraph cables.
- Permeability** (pŭr'mĕ-ă-bil'î-ti): the quality of being easily traversed by magnetic lines of force; susceptibility to magnetism.
- Perpetual motion:** everlasting motion of a hypothetical but mechanically impossible machine that perpetually supplies its own motive force independently of any other outside force.
- Phase:** the position or stage which a periodic phenomenon, such as oscillation or rotation, has reached at a given time, in reference to a given starting position; *Elec.*, a term applied to the number of alternating currents as single phase, where one current flows, or three phase where three alternating currents are flowing, with each one reaching its maximum and minimum intensities at different times.

Phonodeik (fō'nō-dik): an instrument for making photographic records of sound waves in air.

Phonograph: an instrument that reproduces speech, music, or other sounds recorded on a record.

Photoelectric cell: a cell or a vacuum tube of which the electrical properties are modified by the action of light and which uses the photoelectric effect to produce a current.

Photometer (fō-tóm'ê-tēr): an instrument for measuring the intensity of light.

Photons (fō'tōnz): tiny particles of radiations that, according to one theory, consist of tiny bundles of light energy.

Photoradio: the process of transmitting photographs or pictures by radio.

Phototelegraphy: the transmission of photographs or pictures by wire.

Physical change: a change in the form of matter that does not affect its chemical composition.

Physical property: a characteristic that deals only with the form or appearance of a substance.

Physics: the science that deals with matter and energy.

Pilot balloon: a small balloon filled with hydrogen that an observer releases and determines the velocity and direction of the wind.

Piston: a solid disk or cylinder inside a larger hollow cylinder which is moved back and forth in an engine, by the pressure of expanding gas or steam; in a pump, by the force that operates it.

Pitch: *Mus.*, the property of a musical tone that is determined by the frequency of vibration of the sound waves that strike the ear.

Pitch of a screw: the distance between two successive threads.

Pitching: *Aero.*, the up and down motion of the nose of an airplane; rotation about the lateral axis.

Plane: *Aero.*, an airplane.

Plate: *Elec.*, a strip of thin metal placed near the filament and connected to a terminal at the base of a vacuum tube.

Pneumatic (nū-măt'ik): **tubes**: a system of tubes leading to various points and through which letters and packages are sent by air pressure.

Polarity (pō-lār'î-tî): the quality possessed by magnets of having two opposite poles, one north and the other south, each exerting a force opposite to that of the other.

Polarization: an effect produced on the positive electrode of a cell by the depositing on it of bubbles of hydrogen, a nonconducting gas, which increases the resistance and sets up an opposing electromotive force.

Polarized light: light that vibrates in one plane only.

Poles: the ends of the earth's axis or of a magnet; the parts of a magnet that have the greatest attractive power; the points where the lines of force enter and leave the magnet.

Polyphase generator: *Elec.*, one that generates two or more currents not in the same phase.

Porosity: that property of matter which enables it to absorb fluids.

Positive electricity: electricity of which the elementary unit is the proton.

Positron (pōz'î-trōn): a tiny particle charged with positive electricity found in the nucleus of an atom.

Potential: *Elec.*, relating to, or designating, the electric energy that a body possesses by virtue of the electric charge that it carries; the amount of electrical pressure at any point.

Potential energy: the position, condition, or composition of an object or material, that makes possible its capacity for doing work.

Poundal: a unit of force equal to a force that will cause a mass of one pound to accelerate one foot per second each second.

Power: the rate at which an engine, electric motor or other devices do work; the rate of doing work; the amount of work done divided by the time it takes to do it.

Power factor: *Elec.*, in an alternating current, the ratio of the electric power in watts to the apparent power in volt-amperes; the apparent wattage is more than the real wattage.

Precipitation: condensed water vapor in the air which falls to the earth as rain, sleet, snow, or hail; also the process of separating a solid from a solution.

GLOSSARY

Pressure: the push or pull, that is, the force exerted per unit area of the surface acted upon; *Elec.*, electromotive force.

Pressure cooker: an airtight cooking vessel that can be filled with superheated steam under pressure.

Pressure gauge: an instrument for measuring and showing by means of a pointer on a dial the pressure of a confined gas.

Primary battery: an assembly of two or more primary cells.

Primary cell: a voltaic cell, which, when exhausted, is renewable only by replacing some of the materials.

Primary winding: in a transformer or induction coil, the winding in which the current from an outside source flows.

Principal focus: the point at which parallel rays, after striking a lens or mirror, converge or from which they diverge.

Prism: a transparent body bounded in part by two plane faces which are not parallel.

Propeller: two or more blades on a revolving hub or shaft, used to propel an airplane, a boat, or a ship.

Proton (prō'tōn): a component part of the atom charged with positive electricity and complementary to the electron.

Psychrometer (sī-krōm'ê-tēr): an instrument for measuring the humidity in the atmosphere.

Pulley: a wheel with a grooved rim, turning in a frame, and used with a rope or chain for raising weights or loads; a wheel with a broad, flat rim, used with a belt to transmit power.

Pure color: a color that has but one definite wave length.

Pyrometer (pī-rōm'ê-tēr): an instrument used for measuring temperatures beyond the range of mercurial thermometers, such as the temperature of hot furnaces.

Quality of sound: the kind of sound wave that results from the blending of vibrations or the number and intensity of overtones; that property of a tone that distinguishes it from another tone having the same pitch and loudness.

Quartz (kwôrts): a hard mineral, varying from transparent to opaque, in brilliant hexagonal crystals, and composed of silicon dioxide.

Radiant: emitted or transmitted by radiation.

Radiant energy: energy emitted or transmitted by radiation, such as the radiant energy of the sun, which is the great source of heat and light.

Radiation: the transfer of energy waves, as of heat and light, through space at a very high speed and in straight lines; the flow of energy waves in all directions from their source.

Radiator: a body from which rays are sent out; specifically, a body that sends out heat waves.

Radio: a device by which sound waves are transmitted and received without the use of wires; the transmission and reception of signals by means of electric waves without connecting wires.

Radio absolute altimeter: a device for measuring the height of an aircraft above the earth's surface by reflecting electromagnetic waves from the earth below an airplane.

Radio beams: *Aero.*, repeated directional signals sent out from radio range stations on their own wave lengths for the guidance of pilots. After a pilot picks up the signals or beam, he is guided to his destination.

Radio compass: a radio direction finder which is connected to an instrument on whose dial the direction is indicated; a device that makes use of a fixed loop antenna and a visual indicator, and is used principally for flights either toward or away from a radio range station.

Radio frequencies: the frequencies of alternating currents between 20,000 and 300,000 cycles.

Radio interference: the overlapping or intermixing of electric waves from different sending stations, or from atmospheric or other disturbances, resulting in confusion.

Radio range station: *Aero.*, one of a number of radio stations located at airports, and from which radio signals for the guidance of pilots and other information are broadcast.

- Radio transmitter:** an apparatus for sending out radio waves.
- Radio waves:** electromagnetic waves.
- Radioactivity:** the emission of radiant energy; the property possessed by certain elements, chiefly radium, uranium, and thorium, of spontaneously emitting rays of energy.
- Radiogram:** a radio telegram; a message transmitted by radio or wireless telegraphy.
- Radiograph:** a photograph made with the X-ray apparatus.
- Radiometer** (rā'dī-ōm'ē-tēr): an instrument used to measure the intensity of radiant energy, consisting of four vanes, each blackened on one side, and suspended on a pivotal frame, that revolves when exposed to any source of radiant energy.
- Radiophotogram:** a photograph or picture transmitted by radio.
- Radiosonde:** an instrument used to collect meteorological data in high altitudes. It is carried up by a pilot balloon and broadcasts its findings that are picked up by a receiving set on the ground.
- Radium:** an intensely radioactive metallic element found in very minute quantities, principally in pitchblende.
- Rain:** water condensed from water vapor in the atmosphere that overcomes the resistance of the air and falls to the ground in drops.
- Rain gauge:** an instrument for measuring the amount of rainfall.
- Rainbow:** an arc that displays in concentric bands the several colors of the spectrum and that is formed in the sky opposite the sun by the refraction and reflection of the sun's rays as they pass through drops of rain; also, a similar arc formed by the moon.
- Rate-of-climb indicator:** an instrument that indicates the vertical rate of climb of an aircraft by the use of a comparison of air pressures.
- Ratio:** the quotient resulting from dividing one number by another. The quotient represents the ratio between the two numbers.
- Ray:** a beam of radiant energy of very small cross section, as of light, heat, and electricity; also, a line representing the direction of advance of the wave front of heat, light, and electricity.
- Reactance of capacitance:** the opposition offered to the flow of an alternating current by a condenser in the circuit; reactance is measured in ohms.
- Reactance of inductance:** the opposition offered to a changing current in a conductor; reactance is measured in ohms.
- Reaction:** an opposing action produced by another action.
- Real image:** an image formed by the actual focusing of light; an image that can be thrown on a screen.
- Receiver:** that part of a telephone, telegraph, or radio, which changes electrical waves into audible or visible signals.
- Rectifier** (rĕk'tī-fiēr): an apparatus for converting alternating electric current into direct current; a device in a radio receiver for changing electromagnetic waves into sound waves.
- Rectilinear** (rĕk'tī-līn'ē-ēr) **motion:** moving in a straight line.
- Reflection:** the turning back of energy waves from an object, as the reflection of light waves from a mirror, or the throwing out of heat waves from a reflecting heating apparatus, or of sound waves known as echo.
- Reflector:** a polished surface or device for throwing back rays of heat, light, or sound; a device for throwing back heat, light, sound, and electrical waves.
- Reflector telescope:** a telescope in which the rays of light are focused on a huge mirror.
- Refraction** (rĕ-frāk'shŭn): the bending or deflection from a straight path of rays, as of light, in passing obliquely from one medium to another of different density, as from air to water.
- Refractor telescope:** a telescope in which the rays of light that enter the telescope are focused through a transparent lens.

GLOSSARY

- Refrigerant** (rê-frîj'êr-ănt): a substance, such as ice, ammonia, or carbon dioxide, used as a cooling agent.
- Regelation** (rê-jê-lă'shŭn): the refreezing of water that has resulted from the melting of ice due to pressure.
- Regenerative amplification**: *Radio*, the building up of the power in the grid circuit by transferring a part of the power of the plate circuit to the grid circuit.
- Relative humidity**: the ratio of the amount of moisture in the air to the amount of water vapor the air can hold at the given temperature.
- Relative wind**: the direction of air in motion with respect to an airfoil; if an airfoil is moving horizontally east, the relative wind is horizontally west.
- Relay** (rê'lă): *Elec.*, an electromagnetic device by which the opening or closing of one circuit opens or closes another.
- Reluctance**: *Elec.*, the resistance which a substance offers to lines of magnetic force.
- Repeater**: a vacuum-tube amplifier, placed at proper intervals in long-distance telephone transmission lines, for amplifying and retransmitting messages when the original current becomes weak.
- Resistance**: a force that acts to prevent or retard motion; *Elec.*, the opposition offered by a conductor to the passage of an electric current.
- Resistance arm**: that part of a lever with which the resistance is connected.
- Resolution of forces**: the finding of two or more forces that will produce the same result as one force.
- Resonance**: the strengthening and prolonging of a sound by reflection or by the vibration of other objects.
- Resultant force**: one force that will produce the same result as two or more forces.
- Retentivity** (rê'tên-tîv'î-tî): *Elec.*, the property of a substance of retaining magnetism or of resisting magnetization; the property of resisting magnetization or demagnetization.
- Retina** (rê'tî-nă): the inner sensitive coating of the eye that contains the ends of the optic nerve and receives the image of things seen.
- Reverberation**: sound that persists because of repeated reflections after the source of the sound has been cut off.
- Revolution**: the act of passing around a body in a regular orbit.
- Rheostat** (rê'ô-stăt): an instrument for regulating the strength of an electric current by varying the resistance in the circuit.
- Rolling**: *Aero.*, the lifting of one wing and the lowering of the other; rotation about the longitudinal axis.
- Roentgen** (rûnt'gên) **rays**: waves of radiant energy which possess the power of penetrating many opaque substances; X-rays.
- Rotation**: the act of turning on an axis.
- Rotor**: *Elec.*, the rotating member of an electrical machine.
- Rudder**: a broad, flat device hung vertically by hinges to the sternpost of an airplane or vessel and used for steering.
- Safety factor**: the ratio of the ultimate strength of a piece of material to the actual working stress when in use.
- Sal ammoniac**: ammonium chloride, a white crystalline volatile substance with a sharp salty taste.
- Saturated**: the condition of a substance when all the spaces between its molecules are filled with another substance; also the condition when all the molecules of a metal have been magnetized.
- Saturation point**: the point at which the air contains all the water vapor it can hold without ensuing condensation into water.
- Screw**: a modified inclined plane consisting of a cylinder threaded or grooved in an advancing spiral on its outside surface.
- Seaplane**: an airplane provided with pontoons instead of wheels, so that it can travel on water and arise from and alight on it.
- Secondary battery**: *Elec.*, an assembly of two or more secondary cells; also, called storage battery, but as in the case of the secondary cell, electricity is not stored but chemical energy is converted into electrical energy, and the battery may be recharged when exhausted.

- Secondary cell:** *Elec.*, a voltaic cell which, when exhausted, may be recharged by passing a current through it in the reverse direction.
- Secondary winding:** in a transformer or in an induction coil the winding in which voltage is induced by cutting the lines of force of a changing magnetic field.
- Sedimentation:** the settling of solid matter at the bottom of a liquid.
- Semi-indirect lighting:** a system of lighting in which the light is diffused through a medium before it reaches the area to be illuminated.
- Series-wound generator or motor:** a generator or motor in which the armature windings and the field coil are connected in series so that the electric current flows through both the armature and the field coil.
- Shear:** *Mech.*, the condition of a body when a force tends to slide the molecules of a body over each other.
- Sheave:** *Mech.*, a pulley wheel with a grooved rim.
- Shielding:** *Aero.*, the metal shell or covering of all electrical parts of an airplane to prevent the setting up of oscillations which would cause interference in the radio system of the aircraft.
- Short circuit:** the path which an electric current follows when it cuts across between two parts of an electric device because of faulty insulation.
- Shunt:** a conductor that joins two points of an electric circuit over which part of the current may be diverted.
- Shunt-wound generator:** a generator in which the electromagnetic winding and the external circuit are connected in parallel.
- Shunt-wound motor:** a motor in which the armature and the field coils are connected in parallel.
- Simple machines:** the six elementary mechanisms or machine elements: lever, wheel and axle, pulley, inclined plane, wedge, and screw.
- Single-phase current:** a single alternating current.
- Siphon** (*sí'fŏn*): a bent tube or pipe, with unequal arms, used to carry a liquid over a small elevation to a lower level by means of air pressure on the liquid in the container.
- Siren:** an instrument that produces sound by puffs of air that follow in rapid succession.
- Sleet:** frozen rain; rain that passes through a mass of air with a temperature of freezing or below where the rain freezes before it reaches the ground.
- Slug:** *Engin.*, a unit of mass equal to 32.2 pounds; the weight of a body divided by 32.2 equals the number of slugs it contains.
- Solenoid** (*sŏ'lē-noid*): *Elec.*, an insulated wire wound in the form of a coil.
- Solid:** a form of matter in which the molecules are firmly coherent, unyielding, and resistant to ordinary force, and which cannot flow visibly.
- Soluble:** capable of being dissolved in a fluid.
- Solution:** a liquid in which a solid or gas has been dissolved.
- Solvent:** a liquid capable of dissolving a substance.
- Sonic altimeter** (*sŏn'ík ăl-tīm'ê-tēr*): *Aero.*, a device by which reflected sound waves are used to measure the distance from an aircraft to the earth's surface beneath it.
- Sonometer** (*sŏ-nŏm'ê-ter*): an instrument used to measure the frequency of vibrations of strings and to show how they vibrate.
- Sound:** a form of vibrational energy capable of producing sensations through the organs of hearing.
- Sounder:** the receiving instrument of a telegraph set, which consists of an electromagnet with a soft-iron armature attached to a metal bar.
- Snow:** precipitation in the form of hexagonal crystals or flakes of ice frozen in the air from particles of water.
- Space:** that which extends in all directions, has no boundaries, and may be divided indefinitely.
- Spark gap:** the space filled with air between high potential terminals through which the electrical discharge passes.
- Spark plug:** a device in an internal-combustion engine for igniting the gaseous fuel by means of an electric spark discharged within it.
- Specific gravity:** the ratio of the weight of an object in air to the weight of an equal volume of water.

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- Specific heat:** the number of calories required to raise the temperature of one gram of substance one degree Centigrade.
- Specific resistance:** the electrical resistance of a cubic centimeter of any substance offered to a steady current passing between opposite faces.
- Spectroscope:** a device made of prisms and used for breaking up light into a spectrum or band of colors.
- Spectrum** (spĕk'trŭm): the band of colors, namely, red, orange, yellow, green, blue, indigo, and violet, that is formed when light passes through a triangular glass prism.
- Speed:** the rate of motion.
- Speed indicator:** *Aero.*, an instrument which depends on dynamic air pressure to show by means of a pointer on a dial the speed at which an airplane is flying.
- Speedometer** (spĕd-ŏm'ĕ-tēr): a device indicating the rate of speed and the distance traveled.
- Spherical aberration** (sfĕr'ĭ-kāl ăb-ĕr-ă'shŭn): a defect in which, due to the spherical form of a lens or mirror, the central and marginal rays give different foci, and the image is blurred.
- Spinthariscopes** (spĭn-thă'r'ĭ-skŏp): a small instrument to show the emission of particles of radium.
- Stability of an aircraft:** that characteristic which tends to right an aircraft if a disturbing force causes it to leave its course, pitch, or roll.
- Stabilizer:** a device for producing and maintaining the equilibrium of airplanes and ships.
- Stable air:** air that is denser at the bottom than it is at the top, and hence tends to remain as it is.
- Stable equilibrium:** the equilibrium of a body, which, on being slightly displaced, tends to return to its original position.
- Static:** *Radio*, irregular electrical discharges that interfere with the reception of radio signals.
- Static electricity:** the electricity of stationary charges; electrically produced by friction or by induction.
- Stationary engine:** an engine that remains fixed in one place, such as a factory engine.
- Stator** (stă'tēr): the stationary member of an electrical machine; also, the case that encloses a turbine wheel.
- Steam engine:** an engine in which the piston is moved back and forth by the force of steam in the cylinder.
- Steam turbine:** an engine in which the steam acts on a rotor wheel fitted with vanes or buckets, instead of upon a piston.
- Step-down transformer:** a transformer that decreases the voltage of an alternating electric current.
- Step-up transformer:** a transformer that increases the voltage of an alternating electric current.
- Storage battery:** *Elec.*, a connected group of storage cells for generating electric energy by chemical action, in which the cells, after being discharged, may be recharged by passing a direct current through them in a direction opposite to the flow of the current on discharge.
- Storage cell:** *Elec.*, a cell for generating electric current by chemical action, which, after being discharged, may be recharged by passing a direct current through it in the opposite direction.
- Strain:** the amount of change in form or size in a substance produced by force, as by bending, twisting, or stretching.
- Stratosphere** (străt'ŏ-sfēr): the upper portion of the atmosphere, above about seven miles above sea level where the temperature changes but little with altitude and where rain clouds never form.
- Streamlines:** the paths of small particles of a fluid relative to a solid body with respect to which the fluid is moving.
- Streamlined body:** a body which is rounded in front and pointed behind in order to reduce resistance to the relative motion of a fluid, such as the body of an airplane, automobile, ship, or railway engine.
- Stress:** the applied force that produces a strain.
- Sublimation** (sŭb-lĭ-mă'shŭn): the process of changing a substance from a solid directly to a gas, and changing it from a gas back to a solid without going through a liquid state.

Submarine: located or used below the surface of the sea; also, a war vessel which may be operated under water.

Submerge: to sink in a liquid.

Substance: matter: a material object.

Suction: the action by which a partial vacuum is produced.

Suction pump: a lift pump which draws water into the cylinder through air pressure on the surface of the water in the well. At sea level the cylinder must not be more than 34 feet above the surface of the well water.

Supercharger: *Aero.*, a pump that is used to supply more air to the engine than would be supplied normally at the atmospheric pressure at which the aircraft is flying.

Surface tension: the tendency of any liquid surface to act like a stretched elastic film or membrane.

Switch: *Elec.*, a device for breaking or making an electric circuit or current.

Sympathetic vibrations: vibrations set up in a body when its natural vibration rate is the same as that of a near-by sounding body.

Synthesis (sin'thê-sis): the putting together or combining of separate elements into a whole.

Tab: *Aero.*, a small movable section attached to a control surface of an airplane.

Tachometer (tâ-kôm'ê-têr): *Aero.*, an instrument which indicates the revolutions per minute of the engine of an airplane

Tail skid: a small runner or wheel attached under the tail of an airplane to support it when on the ground.

Talking motion pictures: motion pictures that are accompanied by sound, particularly the voices of the actors.

Tangent: a straight line that touches a curved line at only one point.

Telegraph: a device for sending messages for long distances over wire by making and breaking an electric circuit.

Telegraph key: that part of a telegraph instrument that is used for making and breaking the electric circuit.

Telephone: an instrument for transmitting and receiving spoken words and other sound by means of an electric current.

Telephotograph: a photograph or picture transmitted over telephone wires with the aid of special cylinders and the photo-electric cell; also called telephoto, phonephoto, and wire photo.

Telephotography (têl'ê-fô-tôg'râ-fi): the process of electrically transmitting and reproducing photographs or other pictures through a distance.

Telescope: an optical instrument with lenses so adjusted as to make distant objects appear nearer and larger.

Teletype: an electrically operated typewriter by means of which telegraph messages printed in roman letters are sent and received over wires.

Television: the projection to a far distance and reproduction on a screen there of images of a motion picture or of actual objects in action.

Temperature: the degree or amount of heat as measured by a thermometer.

Tenacity: that property of matter, such as chromium or steel, that causes it to have great strength.

Tensile strength: resistance to rupture; the greatest longitudinal stress that a substance can bear without being torn apart, expressed with reference to unit area of cross section.

Terminal: *Elec.*, a device attached to the end of a wire or cable or to a piece of electrical apparatus for convenience in making connections.

Theodolite (thê-ôd'ô-lit): a surveying instrument for measuring horizontal and vertical angles.

Thermionic (thûr'm'î-on'ik) **vacuum tube:** a vacuum-tube amplifier which acts as a repeater and steps up or reinforces the current in long distance telephone lines.

Thermocouple (thûr'mô-kûp'l): a device used to produce an electric current by heating the junction of two different kinds of metals.

Thermograph: a thermometer that makes a graph of temperature changes.

Thermometer: an instrument for measuring changes in temperature.

Thermostat (thûr'mô-stăt): an automatic device for regulating the temperature in a room or building, by opening or closing dampers, or by regulating the amount of fuel that is being burned.

GLOSSARY

- Thrust:** *Aero.*, the force produced by an airplane propeller that is parallel and in the same direction as the motion of the plane.
- Thunder:** the sound that follows a flash of lightning and that is due to the disturbance of the air by the electrical discharge.
- Timer:** *Mech.*, a device in the ignition system of internal-combustion engines, which causes the spark in the cylinder to be produced at the correct time.
- Tire gauge:** a pressure gauge used to test the air pressure in automobile and bicycle tires.
- Tornado** (tôr-nă'dô): a violent whirling storm that travels in a narrow path in the form of an inverted funnel and causes great destruction.
- Torque** (tôrk): a force that tends to produce a rotating or twisting motion; also, the moment of a twisting force.
- Torsion** (tôr'shŭn): the state of being twisted; the amount of twisting.
- Trade wind:** a steady wind that blows continually in the same course or trade from an easterly direction toward the equator; north of the equator the general direction is from northeast to southwest.
- Trailing edge:** *Aero.*, the rear portion of an airfoil, such as the rear edge of a wing or propeller blade.
- Transformer:** *Elec.*, a device that is used for increasing or decreasing, stepping up or stepping down the voltage of an alternating electric current.
- Translucent** (trăns-lŭ'sént): allowing enough light to pass through to let objects be seen indistinctly.
- Transmission:** *Radio*, the passing of radio waves in the space between sending and receiving stations.
- Transmission system:** the parts of an automobile by means of which the power of the engine is transferred to the axles of the wheels.
- Transmitter:** a device used for sending out or transmitting; in case of the telephone, the part into which one speaks; in case of the telegraph, that part of the equipment used for sending messages; in case of the radio, a transmitting set, also a transmitting station.
- Transparent:** allowing light to pass through without diffusion, so that objects behind may be seen distinctly.
- Transverse waves:** those waves in which the particles move at right angles to the direction of the motion.
- Triode:** a three-element vacuum tube that contains a positive electrode, a negative electrode, and a grid.
- Troposphere** (tröp'ô-sfēr): *Meteorol.*, the lower layer of the atmosphere which extends to about six to eight miles above the surface of the earth and in which weather phenomena occur.
- Tune in:** *Radio*, to adjust a receiving set so as to hear the program of a given broadcasting station.
- Tungsten** (tŭng'stĕn): a hard, heavy, grayish white metal of the chromium group, with the highest melting point of any of the metals, used for electric light filaments and to increase the hardness of steel.
- Tuning:** *Radio*, a method of adjusting the current in a radio receiving set, so that a radio signal of desired frequency may be selected and all signals of interfering frequencies may be rejected; also, adjusting a musical instrument to a correct musical pitch.
- Tuning fork:** a fork-shaped piece of steel with two equal prongs, which, when struck, vibrate so as to give a tone of a certain pitch.
- Turbine** (tŭr'bin): a form of motor in which the power is derived from water or steam driven against curved vanes or cups on the rim of a wheel.
- Two-cycle engine:** an internal-combustion engine in which compression and expansion of the charge is effected during one stroke, and the exhaust of the burnt gases and the suction of the fresh charge, by the second stroke.
- Ultimate strength:** *Mech.*, the limit of resistance of a material to a stress before rupture is caused.
- Umbra** (ŭm'bră): the darkest portion of a shadow which is cut off completely from light of the source.
- Uniform:** devoid of change or variation, such as uniform velocity, uniform acceleration, or uniform temperature.

Universe: the whole system of existing material things.

Unstable air: air that is less dense at the bottom than it is at the top, a condition that results in movement because the denser air pushes the less dense away from the bottom.

Unstable equilibrium: the condition of a body when its center of gravity is lowered as the body is tipped.

Vacuum: (vǎk'û-ûm): a space from which all air has been withdrawn; a space that is nearly empty.

Vacuum bottle: a device consisting of two bottles, one inside the other, with a vacuum between them, used for keeping cold substances cold and hot substances hot; a thermos bottle.

Vacuum cleaner: a machine that operates on the same principle as the vacuum pump and which makes use of suction for cleaning carpets, rugs, drapes, and other upholstery.

Vacuum pump: an air pump used to withdraw air from a closed container.

Vacuum tube: a glass blub in which a filament heated by a negative charge of electricity sets up a positive charge on a cold electrode; used as a radio detector.

Valve: a mechanical device for opening and closing a canal, pipe, or tube for carrying fluids, and thus regulating or directing the movement of water, gas, or other fluids.

Vapor: a gaseous form of a liquid or a solid.

Vaporization: act or process of changing liquids into vapor, such as changing water into steam.

Vaporize: to convert a liquid into vapor through heat or other process.

Vapor pressure: the pressure of a vapor when in contact with a solid or liquid state of the same substance; the pressure exerted by the molecules of vapor which increases with the increase of temperature of the substance.

Vehicle (vĕ'y-k'l): that in which or on which a thing is carried.

Velocity: rate of motion; time rate of motion in a given direction.

Velocity ratio: the ratio of the velocity of the effort to the velocity of the resistance.

Venturi (vĕn-tōō'rĕ) **tube:** a tube with a narrow throat, in which the speed of fluids passing through it increases and their pressure against the side of the tube at the throat decreases.

Vibration: periodic motion to and fro, as of a pendulum, tuning fork, or waves.

Vibration frequency: rate of vibration.

View finder: an attachment on a photographic camera which represents in miniature the view to be photographed, and by means of which the camera is adjusted.

Virtual focus: the point from which the rays of light seem to diverge after passing through a lens.

Virtual image: one formed of virtual foci, as one seen in a plane mirror.

Visibility: *Aero.*, the greatest distance toward the horizon at which prominent objects may be recognized by the normal eye.

Vision: the sense by which light and color are perceived; the act of seeing external objects.

Volatile (vōl'ā-tīl): evaporating very rapidly at ordinary temperatures.

Volt: the amount of electric pressure, called electromotive force, required to push an ampere of current through a resistance of one ohm.

Voltage (vōl'tāj): electrical pressure or electromotive force measured in volts.

Voltaic (vōl-tā'ik) **cell:** a simple cell, invented by Volta, that has copper or carbon for the positive electrode and zinc for the negative electrode, and a solution of sulfuric acid or of sal ammoniac as the electrolyte.

Voltmeter: an instrument for measuring in volts the differences of potential between different points of an electric circuit.

Volume: that property of matter which relates to the amount of measurable space that a substance occupies.

Water wheel: a wheel equipped with vanes, paddles, buckets, or cups and turned by the force of water.

Waterhead: a vertical column of water from any point beneath the surface of the water to the plane of the surface.

GLOSSARY

Watt: the unit of measurement that shows the rate at which an electric current is doing work; 746 watts are about equal to one horse power. Watt = amperes $\times$ volts.

Wattage: the amount of electric power expressed in watts.

Watt-hour: a unit of electric energy, equal to the work done by one watt in one hour.

Watt-hour meter: an instrument for recording on dials the number of kilowatt hours of electricity consumed.

Wattmeter: an instrument for measuring directly the electric power in a circuit. The wattmeter measures the power of the electric current; the watt-hour meter records the amount of electrical energy consumed.

Watt-second: a unit of power equal to one watt per second.

Wave: a single pulse, or the disturbance included in one unit length of the advance of a disturbance into a medium, such as a water wave, a sound wave, a light wave, or an electromagnetic wave.

Wave length: the distance between two corresponding points in any two adjacent waves.

Weather map: *Meteorol.*, a map of a region or a country, such as the United States, on which weather conditions, as they exist at the time of observation, are indicated.

Wedge: a simple machine in the form of two movable inclined planes placed base to base, used by applying effort at the head to overcome resistance, that acts on the slanting sides.

Weight: that property of matter which measures the earth's attraction, indicated by a pull toward its center known as gravity.

Westphal (west'fôl) balance: an instrument that shows the buoyancy of floats by means of sliding weights on a balance arm.

Wet- and dry-bulb thermometers: instruments for measuring the humidity of the air.

Wet cell: an electric cell in which the electrolyte consists of a chemical solution. See Voltaic cell.

Wheatstone bridge: *Elec.*, a device used to find the resistance of a conductor of electricity.

Wheel and axle: a wheel or crank mounted on an axle, both of which move about the same axis.

Wind: air in motion caused by the unequal temperature of the atmosphere.

Wind direction: the direction from which the wind is moving.

Wind tunnel: an apparatus in the form of a venturi tube in which is produced an artificial air stream, in which objects, such as airfoils, are placed to investigate the air flow about them.

Wing: *Aero.*, one of the main supporting surfaces of an airplane that extends at right angles to the fuselage and helps to sustain the airplane in the air.

Wireless telegraphy: a system of telegraphy in which no wires are used between the sending and receiving stations.

Work: movement against a resisting force, measured by the product of the force and the distance through which it acts.

X-rays: rays produced by an electric discharge in a vacuum tube, similar to a light ray but of very short wave length, capable of penetrating many opaque substances, and used in photographing inner parts of the body and in the treatment of certain diseased conditions of the tissues.

Yawing: *Aero.*, the turning of an aircraft to the right or left; rotation about the normal axis.

Zeppelin (zēp'ê-lîn): a large dirigible airship with a metal frame.

Appendix

ABBREVIATIONS OF TERMS USED IN PHYSICS

(The abbreviation stands for both the singular and the plural forms.)

A.C.....	alternating current	Dm.....	decameter
Aero.....	aeronautics	dm.....	decimeter
A.F.....	audio frequency	e.....	erg
a.h.....	ampere hour	elec.....	electric; electricity
alt.....	altitude	elev.....	elevation
A. M.....	amplitude	E.M.F.; e.m.f.	electromotive force
	modulation	F.....	Fahrenheit
amp.....	ampere; amperage	f.f.....	fixed focus
arm.....	armature	F.M.....	frequency
at.....	atmosphere; atomic		modulation
bar.....	barometer; baro-	freq. m.....	frequency meter
	metric	ft.....	foot
B. and S.....	Brown and Sharpe	ft.-c.....	foot-candle
b.p.....	boiling point	ft.-lb.....	foot-pound
B.t.u.....	British thermal	g.....	gram
	unit	gal.....	gal.
C.....	coulomb	g.-cal.....	gram-calorie
C.....	Centigrade	gen.....	generator
cal.....	small calorie	g.p.m.....	gallons per minute
Cal.....	large calorie	gr.....	grain
c.c.....	cubic centimeter	H.....	henry
cg.....	centigram	ha.....	hectare
C.G.S.....	centimeter-gram-	hg.....	hectogram
	second system	H.F.....	high frequency
cl.....	centiliter	hl.....	hectoliter
cm.....	centimeter	hm.....	hectometer
C.P.....	candle power	HP.....	horsepower
cu.....	cubic	hr.....	hour
cu. in.....	cubic inch	ht.....	height
D.....	density	in.....	inch
d.....	dyne	ins.....	insulator
db.....	decibel	J.....	joule
D.C.....	direct current	K.....	temperature on the
deg.....	degree		Kelvin scale
Dg.....	decagram	kc.....	kilocycles
dg.....	decigram	kg.....	kilogram
Dl.....	decaliter	kl.....	kiloliter
dl.....	deciliter	km.....	kilometer

APPENDIX

kw.....	kilowatt	pt.....	pint
K.W.H.....	kilowatt hour	R.....	resistance
l.....	liter	rd.....	rod
lb.....	pound	r.p.m.....	revolutions per minute
L.F.....	low frequency	r.p.s.....	revolutions per second
M.....	mass; moment; thousand	sec.....	second
m.....	meter	sp. gr.	specific gravity
Ma.....	milliampere	sp. ht.....	specific heat
mb.....	millibar	sq.....	square
mf.....	millifarad	S.W.G.....	standard wire gauge
mg.....	milligram	t.....	time; tension
mh.....	millihenry	tech.....	technical
mi.....	mile	temp.....	temperature
min.....	minute	V.....	volume
m-kg.....	meter-kilogram	V.....	volt
ml.....	milliliter	v.d.....	vapor density
mm.....	millimeter	vm.....	voltmeter
m.p.h.....	miles per hour	watt-hr.....	watt-hour
M.T.....	metric ton	W.G.....	wire gauge
mv.....	millivolt	wt.....	weight
o.....	ohm	yd.....	yard
P.....	pressure		
P.D.....	potential differences		

TABLES

TABLE I. Some Convenient Formulas and Equivalents

1 cubic centimeter of pure water at 4° C. weighs 1 gram

1 cubic foot of water at 4° C. weighs 62.4 pounds.

1 liter of water at 4° C. weighs 1 kilogram.

1 gallon of pure water at 4° C. weighs 8.3 pounds.

$$\text{Area of a triangle} = \frac{\text{base} \times \text{altitude}}{2}$$

$$\text{Circumference of a circle} = 2\pi r$$

$$\text{Area of a circle} = \pi r^2$$

$$\text{Area of a sphere} = 4\pi r^2$$

$$\text{Volume of a sphere} = \frac{4}{3}\pi r^3$$

$$\text{Entire area of a cylinder} = \frac{(\text{area of bases})}{2\pi r^2} + \frac{(\text{lateral area})}{2\pi r h}$$

$$\text{Volume of a cylinder} = \pi r^2 h$$

Atmospheric pressure at standard conditions = 14.7 lb. per sq. in. or 1033.3 g. per sq. cm. or 76 cm. of mercury or 30 inches of mercury.

APPENDIX

TABLE II. Equivalents of Units of the American and of the Metric Systems of Measures

MEASURES OF LENGTH

1 in. = 2.54 cm.	1 cm. = .3937 in.
1 ft. = 30.48 cm.	1 m. = 39.37 in.
1 ft. = .3048 m.	1 m. = 3.28 ft.
1 yd. = .9144 m.	1 m. = 1.093 yd.
1 rd. = 5.029 m.	1 km. = 3280.7 ft.
1 mi. = 1.609 km.	1 km. = .621 mi.

MEASURES OF SURFACE

1 sq. in. = 6.451 sq. cm.	1 sq. mm. = .00155 sq. in.
1 sq. ft. = 929.00 sq. cm.	1 sq. cm. = .155 sq. in.
1 sq. yd. = .8361 sq. m.	1 sq. dm. = 15.5 sq. in.
1 sq. rd. = 25.293 sq. m.	1 sq. m. = 1550 sq. in.
1 acre = .4047 hectare	1 sq. m. = 10.764 sq. ft.
1 sq. mi. = 2.59 sq. km.	1 are = 119.6 sq. yd.
	1 hectare = 2.471 acres
	1 sq. km. = .3861 sq. mi.

MEASURES OF VOLUME

1 cu. in. = 16.387 c.c.	1 c.c. = .061 cu. in.
1 cu. ft. = 28,315.35 c.c.	1 cu. m. = 35.314 cu. ft.
1 cu. ft. = .0283 cu. m.	1 cu. m. = 1.3079 cu. yd.
1 cu. yd. = .7646 cu. m.	1 cu. m. = 264.18 gal.

MEASURES OF CAPACITY

1 fluid dram = 3.70 c.c.	1 ml. = .2705 fluid dram
1 fluid oz. = 29.57 c.c.	1 cl. = .3381 fluid oz.
1 gill = .118 liter	1 dl. = .8454 gill
1 pt. = .4732 liter	1 liter = 1.0567 qt. (liquid)
1 qt. (liquid) = .9463 liter	1 Dl. = 2.6418 gal.
1 gal. = 3.785 liter	1 hl. = 26.418 gal.
	1 kl. = 264.18 gal.

MEASURES OF MASS (WEIGHT)

1 grain = 64.8 mg.	1 mg. = .0154 grain
1 oz. (av.) = 28.35 g.	1 cg. = .1543 grain
1 lb. (av.) = 453.6 g.	1 dg. = 1.543 grains
1 lb. (av.) = .4536 kg.	1 g. = 15.432 grains
1 cwt. (av.) = 45.36 kg.	1 g. = .03527 oz. (av.)
1 short ton = .9072 M.T.	1 Dg. = .3527 oz. (av.)
	1 hg. = 3.527 oz. (av.)
	1 kg. = 35.27 oz. (av.)
	1 kg. = 2.2046 lb. (av.)
	1 quintal = 220.46 lb. (av.)
	1 M.T. = 2204.6 lb. (av.)

APPENDIX

TABLE III. Formulas that Aid in Making Conversions from the Metric to the American and from the American to the Metric System of Measures

MEASURES OF LENGTH

cm. $\times$.3937 = in.	in. $\times$ 2.54 = cm.
m. $\times$ 39.37 = in.	in. $\div$ 39.37 = m.
m. $\times$ 3.28 = ft.	ft. $\div$ 3.28 = m.
m. $\times$ 1.094 = yd.	yd. $\div$ 1.094 = m.
km. $\times$.6213 = mi.	mi. $\times$ 1.609 = km.

MEASURES OF SURFACE

sq. cm. $\times$.155 = sq. in.	sq. in. $\times$ 6.45 = sq. cm.
sq. m. $\times$ 10.764 = sq. ft.	sq. ft. $\div$ 10.764 = sq. m.
sq. m. $\times$ 1.196 = sq. yd.	sq. yd. $\div$ 1.196 = sq. m.
hectares $\times$ 2.471 = acres	acres $\div$ 2.471 = hectares
sq. km. $\times$.3861 = sq. mi.	sq. mi. $\div$.3861 = sq. km.

MEASURES OF VOLUME

cu. m. $\times$ 35.314 = cu. ft.	cu. in. $\times$ 16.387 = c.c.
cu. m. $\times$ 1.308 = cu. yd.	cu. ft. $\div$ 35.314 = cu. m.
cu. m. $\times$ 264.2 = gal.	cu. yd. $\div$ 1.308 = cu. m.

MEASURES OF CAPACITY

liters $\times$.264 = gal.	gal. $\div$.264 = liters
liters $\times$ 1.056 = qt.	gal. $\times$ 3.78 = liters
hl. $\times$ 26.42 = gal.	gal. $\div$ 26.42 = hl.
hl. $\times$ 2.84 = bu.	bu. $\div$ 2.84 = hl.

MEASURES OF MASS (WEIGHT)

g. $\times$ 15.432 = grains	oz. $\times$ 28.35 = g.
kg. $\times$ 35.3 = oz.	oz. $\div$ 35.3 = kg.
kg. $\times$ 2.2046 = lb.	lb. $\div$ 2.2046 = kg.
quintals $\times$ 220.46 = lb.	lb. $\div$ 220.46 = quintals
M.T. $\times$ 2204.6 = lb.	cw ^t . $\times$ 45.36 = kg.

TABLE IV. Equivalents of Units of Work or Energy

1 HP. = 33,000 ft.-lb. per minute	1 B.t.u. = 778 ft.-lb.
1 HP. = 550 ft.-lb. per second	1 cal. = 427 gram-meters
1 HP. = 746 watts	1 Cal. = 3.968 B.t.u.
1 ft.-lb. = 13,560,000 ergs	1 dyne = $\frac{1}{980}$ of a gram force
1 J = 10,000,000 ergs	1 poundal = $\frac{1}{32.16}$ of a pound force
1 J = .738 ft.-lb.	
1 B.t.u. = 252 cal.	1 poundal = 13,825 dynes

APPENDIX

TABLE V. Density in Grams Per Cubic Centimeter

Air, at 0° C. and 76 cm. mercury pressure.....	0.00129	Ice.....	0.92
Alcohol.....	0.81	Iron (pure).....	7.8
Aluminum.....	2.67	Iron (wrought).....	7.8 to 7.9
Brass.....	8.4 to 8.7	Iron (steel).....	7.7 to 7.9
Charcoal.....	.6	Lead.....	11.4
Coal (anthracite).....	1.3 to 1.8	Mercury.....	13.6
Coal (bituminous).....	1.2 to 1.4	Milk.....	1.03
Copper.....	8.8	Nickel.....	8.9
Cork.....	0.24	Paraffin.....	0.9
Diamond.....	3.0 to 3.5	Platinum.....	21.5
Ether.....	0.74	Silver.....	10.5
Gasoline.....	0.66 to 0.69	Sulfuric acid.....	1.84
German silver.....	8.4	Tin.....	7.3
Glass (crown).....	2.6	Tungsten.....	18.6 to 19.1
Glass (flint).....	3.0 to 6.0	Water at 4° C.....	1.00
Glycerine.....	1.26	Water (sea).....	1.03
Gold.....	19.3	Zinc.....	7.1

Note: The above table gives the weight in grams of one cubic centimeter of the substance. Since one cubic centimeter of water at 4° C. weighs one gram and specific gravity is the ratio of the weight of a substance to the weight of an equal volume of water at 4° C., the specific gravity of the above substances is numerically the same as the weight of one cubic centimeter of the substances. The specific gravity of a substance is an abstract number and is the same in both English and metric systems.

TABLE VI. Weight of United States Coins

50 centpiece (half dollar) weighs 12.5 grams	10 cent piece (dime) weighs 2.5 grams
25 cent piece (quarter) weighs 6.25 grams	5 cent piece (nickel) weighs 5.0 grams

TABLE VII. Coefficient of Linear Expansion per Degree Centigrade Scale

Aluminum.....	0.000023	Glass.....	0.000008
Brass.....	0.000018	Iron and steel.....	0.000012
Copper.....	0.000017	Zinc.....	0.000029

TABLE VIII. Heat Values of Fuels

<i>Fuel</i>	<i>B.t.u. per Pound</i>	<i>Fuel</i>	<i>B.t.u. per Pound</i>
Charcoal.....	16000	Oil (fuel).....	18000
Coal (bituminous).....	11000-14000	Gasoline.....	20000
Coal (semibituminous).....	14000-14700	Natural Gas.....	1000 B.t.u. per cu. ft.
Coal (anthracite).....	12500-13400	Manufactured Gas.....	600 B.t.u. per cu. ft.

APPENDIX

TABLE IX. Grams of Water Vapor Required to Saturate Air per Cubic Meter

<i>Temp. C°</i>	<i>Grams</i>	<i>Temp. C°</i>	<i>Grams</i>	<i>Temp. C°</i>	<i>Grams</i>
0°	4.84	11	9.94	22	19.22
1	5.18	12	10.57	23	20.36
2	5.54	13	11.25	24	21.55
3	5.92	14	11.96	25	22.80
4	6.33	15	12.71	26	24.11
5	6.76	16	13.50	27	25.49
6	7.22	17	14.34	28	26.93
7	7.70	18	15.22	29	28.45
8	8.22	19	16.14	30	30.04
9	8.76	20	17.12	31	31.70
10	9.33	21	18.14	32	33.50

TABLE X. Melting and Boiling Points at 76 cm. Pressure

<i>Substance</i>	<i>Melting Point C°</i>	<i>Boiling Point C°</i>
Alcohol (ethyl).....	— 130	78
Aluminum.....	658	1800
*Carbon.....	3500	4200
Helium.....	— 271	— 267
Hydrogen.....	— 259	— 252
Mercury.....	— 38.9	357
Platinum.....	1755	3910
Water.....	0°	100
Tungsten.....	3400	5830

* Sublimes at temperature above 3500° C.

TABLE XI. Specific Heats and Melting Points

	<i>Specific Heats</i>		<i>Melting Points Temp. Centigrade</i>
Aluminum.....	0.22	Aluminum.....	658
Brass.....	0.095	Ice.....	0°
Copper.....	0.09	Iron.....	1100 to 1200
Glass.....	0.2	Mercury.....	— 38.9
Ice.....	0.5	Platinum.....	1755
Iron.....	0.113	Rose's metal.....	94
Lead.....	0.03	Solder.....	225
Mercury.....	0.03	Tungsten.....	3400
Silver.....	0.06		
Steam (100° C. at 76 cm. pressure).....	0.48		
Water.....	1.00		
Zinc.....	0.095		

TABLE XII. B. and S. Gauge, Diameter, and Resistance of Soft Copper Wires

B. AND S. GAUGE NO.	DIAMETER IN MILS (d)	OHMS PER 1000 FT. AT 20° C. OR 68° F.	B. AND S. GAUGE NO.	DIAMETER IN MILS (d)	OHMS PER 1000 FT. AT 20° C. OR 68° F.
0000....	460.00	0.049	19....	35.89	8.051
000....	409.64	0.0618	20....	31.96	10.14
00....	364.80	0.0779	21....	28.46	12.78
0....	324.95	0.983	22....	25.35	16.12
1....	289.30	0.124	23....	22.57	20.36
2....	257.63	0.156	24....	20.10	25.63
3....	229.42	0.197	25....	17.90	32.31
4....	204.31	0.248	26....	15.94	40.75
5....	181.94	0.313	27....	14.20	51.38
6....	162.02	0.395	28....	12.64	64.79
7....	144.28	0.498	29....	11.26	81.70
8....	128.49	0.628	30....	10.03	103.0
9....	114.43	0.792	31....	8.93	129.9
10....	101.89	0.999	32....	7.95	163.8
11....	90.74	1.257	33....	7.08	206.6
12....	80.81	1.586	34....	6.31	260.5
13....	71.96	2.003	35....	5.62	328.4
14....	64.08	2.525	36....	5.00	414.8
15....	57.07	3.184	37....	4.45	523.2
16....	50.82	4.016	38....	3.97	659.6
17....	45.26	5.064	39....	3.53	831.8
18....	40.30	6.385	40....	3.15	1049.0

The resistance of a mil-foot of copper = 10.4 ohms.

The resistance of a mil-foot of German silver = 180 ohms to 218 ohms.

The resistance of a mil-foot of nichrome = 600 ohms to 660 ohms.

The resistance of 1000 ft. of German silver or nichrome is found by multiplying the resistance of copper as given in the table by the resistance of one mil-foot of German silver or nichrome and dividing the result by 10.4.

Example. Find the resistance of 1000 ft. of No. 10 German silver wire.

Solution. $0.999 \times \frac{180}{10.4} = 17.2$ ohms.

TABLE XIII. Indices of Refraction

Canada balsam.....	1.50	Glass (flint).....	1.62
Carbon disulphide.....	1.64	Ice.....	1.31
Diamond.....	2.47	Water.....	1.33
Glass (crown).....	1.52		

APPENDIX

TABLE XIV. Comparison of Barometric Reading in Inches and Altitude above Sea Level in Feet

Devised by Sir George Biddell Airey, K. C. B., Astronomer Royal of Great Britain

ANEROID OR COR- RECTED BAR- OMETER	HEIGHT IN FEET	ANEROID OR COR- RECTED BAR- OMETER	HEIGHT IN FEET	ANEROID OR COR- RECTED BAR- OMETER	HEIGHT IN FEET	ANEROID OR COR- RECTED BAR- OMETER	HEIGHT IN FEET	ANEROID OR COR- RECTED BAR- OMETER	HEIGHT IN FEET
IN.	Ft.	IN.	Ft.	IN.	Ft.	IN.	Ft.	IN.	Ft.
31.00	0	28.28	2500	25.80	5000	23.54	7500	21.47	10000
30.94	50	28.23	2550	25.75	5050	23.50	7550	21.44	10050
30.88	100	28.18	2600	25.71	5100	23.45	7600	21.40	10100
30.83	150	28.12	2650	25.66	5150	23.41	7650	21.36	10150
30.77	200	28.07	2700	25.61	5200	23.37	7700	21.32	10200
30.71	250	28.02	2750	25.56	5250	23.32	7750	21.28	10250
30.66	300	27.97	2800	25.52	5300	23.28	7800	21.24	10300
30.60	350	27.92	2850	25.47	5350	23.24	7850	21.20	10350
30.54	400	27.87	2900	25.42	5400	23.20	7900	21.16	10400
30.49	450	27.82	2950	25.38	5450	23.15	7950	21.12	10450
30.43	500	27.76	3000	25.33	5500	23.11	8000	21.08	10500
30.38	550	27.71	3050	25.28	5550	23.07	8050	21.05	10550
30.32	600	27.66	3100	25.24	5600	23.03	8100	21.01	10600
30.26	650	27.61	3150	25.19	5650	22.98	8150	20.97	10650
30.21	700	27.56	3200	25.15	5700	22.94	8200	20.93	10700
30.15	750	27.51	3250	25.10	5750	22.90	8250	20.89	10750
30.10	800	27.46	3300	25.05	5800	22.86	8300	20.85	10800
30.04	850	27.41	3350	25.01	5850	22.82	8350	20.82	10850
29.99	900	27.36	3400	24.96	5900	22.77	8400	20.78	10900
29.93	950	27.31	3450	24.92	5950	22.73	8450	20.74	10950
29.88	1000	27.26	3500	24.87	6000	22.69	8500	20.70	11000
29.82	1050	27.21	3550	24.82	6050	22.65	8550	20.66	11050
29.77	1100	27.16	3600	24.78	6100	22.61	8600	20.63	11100
29.71	1150	27.11	3650	24.73	6150	22.57	8650	20.59	11150
29.66	1200	27.06	3700	24.69	6200	22.52	8700	20.55	11200
29.61	1250	27.01	3750	24.64	6250	22.48	8750	20.51	11250
29.55	1300	26.96	3800	24.60	6300	22.44	8800	20.47	11300
29.50	1350	26.91	3850	24.55	6350	22.40	8850	20.44	11350
29.44	1400	26.86	3900	24.51	6400	22.36	8900	20.40	11400
29.39	1450	26.81	3950	24.46	6450	22.32	8950	20.36	11450
29.34	1500	26.76	4000	24.42	6500	22.28	9000	20.32	11500
29.28	1550	26.72	4050	24.37	6550	22.24	9050	20.29	11550
29.23	1600	26.67	4100	24.33	6600	22.20	9100	20.25	11600
29.17	1650	26.62	4150	24.28	6650	22.16	9150	20.21	11650
29.12	1700	26.57	4200	24.24	6700	22.11	9200	20.18	11700
29.07	1750	26.52	4250	24.20	6750	22.07	9250	20.14	11750
29.01	1800	26.47	4300	24.15	6800	22.03	9300	20.10	11800
28.96	1850	26.42	4350	24.11	6850	21.99	9350	20.07	11850
28.91	1900	26.37	4400	24.06	6900	21.95	9400	20.03	11900
28.86	1950	26.33	4450	24.02	6950	21.91	9450	19.99	11950
28.80	2000	26.28	4500	23.97	7000	21.87	9500	19.95	12000
28.75	2050	26.23	4550	23.93	7050	21.83	9550	19.241	13000
28.70	2100	26.18	4600	23.89	7100	21.79	9600	18.548	14000
28.64	2150	26.13	4650	23.84	7150	21.75	9650	17.880	15000
28.59	2200	26.09	4700	23.80	7200	21.71	9700	17.235	16000
28.54	2250	26.04	4750	23.76	7250	21.67	9750	16.615	17000
28.49	2300	25.99	4800	23.71	7300	21.63	9800	16.016	18000
28.43	2350	25.94	4850	23.67	7350	21.59	9850	15.439	19000
28.38	2400	25.89	4900	23.62	7400	21.55	9900	14.883	20000
28.33	2450	25.85	4950	23.58	7450	21.51	9950		

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TABLE XV. Relative Humidity Tables

Per Cent Fahrenheit Temperatures

DIFFERENCE IN DEGREES BETWEEN WET- AND DRY-BULB THERMOMETERS

Reading of dry bulb thermometer	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0
32	90	79	69	60	50	41	31	22	13	4							
33	90	80	71	61	52	42	33	24	16	7							
34	90	81	72	62	53	44	35	27	18	9	1						
35	91	82	73	64	55	46	37	29	20	12	4						
36	91	82	73	65	56	48	39	31	23	14	6						
37	91	83	74	66	58	49	41	33	25	17	9	1					
38	91	83	75	67	59	51	43	35	27	19	12	4					
39	92	84	76	68	60	52	44	37	29	21	14	7					
40	92	84	76	68	61	53	46	38	31	23	16	9	2				
41	92	84	77	69	62	54	47	40	33	26	18	11	5				
42	92	85	77	70	62	55	48	41	34	28	21	14	7				
43	92	85	78	70	63	56	49	43	36	29	23	16	9	3			
44	93	85	78	71	64	57	51	44	37	31	24	18	12	5			
45	93	86	79	71	65	58	52	45	39	33	26	20	14	8	2		
46	93	86	79	72	65	59	53	46	40	34	28	22	16	10	4		
47	93	86	79	73	66	60	54	47	41	35	29	23	17	12	6	1	
48	93	87	80	73	67	60	54	48	42	36	31	25	19	14	8	3	
49	93	87	80	74	67	61	55	49	43	37	32	26	21	15	10	5	
50	93	87	81	74	68	62	56	50	44	39	33	28	22	17	12	7	2
51	94	87	81	75	69	63	57	51	45	40	35	29	24	19	14	9	4
52	94	88	81	75	69	63	58	52	46	41	36	30	25	20	15	10	6
53	94	88	82	75	70	64	58	53	47	42	37	32	27	22	17	12	7
54	94	88	82	76	70	65	59	54	48	43	38	33	28	23	18	14	9
55	94	88	82	76	71	65	60	55	49	44	39	34	29	25	20	15	11
56	94	88	82	77	71	66	61	55	50	45	40	35	31	26	21	17	12
57	94	88	83	77	72	66	61	56	51	46	41	36	32	27	23	18	14
58	94	89	83	77	72	67	62	57	52	47	42	38	33	28	24	20	15
59	94	89	83	78	73	68	63	58	53	48	43	39	34	30	25	21	17
60	94	89	84	78	73	68	63	58	53	49	44	40	35	31	27	22	18
61	94	89	84	79	74	68	64	59	54	50	45	40	36	32	28	24	20
62	94	89	84	79	74	69	64	60	55	50	46	41	37	33	29	25	21
63	95	90	84	79	74	70	65	60	56	51	47	42	38	34	30	26	22
64	95	90	85	79	75	70	66	61	56	52	48	43	39	35	31	27	23
65	95	90	85	80	75	70	66	62	57	53	48	44	40	36	32	28	25
66	95	90	85	80	76	71	66	62	58	53	49	45	41	37	33	29	26
67	95	90	85	80	76	71	67	62	58	54	50	46	42	38	34	30	27
68	95	90	85	81	76	72	67	63	59	55	51	47	43	39	35	31	28
69	95	90	86	81	77	72	68	64	59	55	51	47	44	40	36	32	29

APPENDIX

TABLE XV. Relative Humidity Tables
(Continued)

Reading of dry bulb thermometer	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0
70	95	90	86	81	77	72	68	64	60	56	52	48	44	40	37	33	30
71	95	90	86	82	77	73	69	64	60	56	53	49	45	41	38	34	31
72	95	91	86	82	78	73	69	65	61	57	53	49	46	42	39	35	32
73	95	91	86	82	78	73	69	65	61	58	54	50	46	43	40	36	33
74	95	91	86	82	78	74	70	66	62	58	54	51	47	44	40	37	34
75	96	91	87	82	78	74	70	66	63	59	55	51	48	44	41	38	34
76	96	91	87	83	78	74	70	67	63	59	55	52	48	45	42	38	35
77	96	91	87	83	79	75	71	67	63	60	56	52	49	46	42	39	36
78	96	91	87	83	79	75	71	67	64	60	57	53	50	46	43	40	37
79	96	91	87	83	79	75	71	68	64	60	57	54	50	47	44	41	37
80	96	91	87	83	79	76	72	68	64	61	57	54	51	47	44	41	38
82	96	92	88	84	80	76	72	69	65	62	58	55	52	49	46	43	40
84	96	92	88	84	80	77	73	70	66	63	59	56	53	50	47	44	41
86	96	92	88	85	81	77	74	70	67	63	60	57	54	51	48	45	42
88	96	92	88	85	81	78	74	71	67	64	61	58	55	52	49	46	43
90	96	92	89	85	81	78	75	71	68	65	62	59	56	53	50	47	44
92	96	92	89	85	82	78	75	72	69	65	62	59	57	54	51	48	45
94	96	93	89	86	82	79	75	72	69	66	63	60	57	54	52	49	46
96	96	93	89	86	82	79	76	73	70	67	64	61	58	55	53	50	47
98	96	93	89	86	83	79	76	73	70	67	64	61	59	56	53	51	48
100	96	93	90	86	83	80	77	74	71	68	65	62	59	57	54	52	49

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